A NOVEL STRATEGY TO REDUCE EXERCISE-INDUCED HYPERTHERMIA IN DIFFERENT AGE GROUPS

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SUMMARY

Exercise and heat stress

The limitations to exercise performances have been a matter of interest that have fascinated humans throughout history. There are a number of factors that may influence the capacity of an individual to perform prolonged exercise, one of which is ambient temperature.[1] In 1916, Lee and Scott [2] were the first scientists who observed an early fatigue in cats during exercise in a hot environment. Although their results were inconclusive, they were the first authors to report that exercising in the heat leads to a premature fatigue. Following research done in humans, demonstrated that endurance could be impaired in hot environments when compared to temperate climates.[1, 3, 4] As an example, Parkin at al.[4] investigated the effects of three different ambient temperatures (3, 20 and 40ºC) on exercise performance during fatiguing submaximal exercise (70% peak pulmonary oxygen uptake). Authors observed a progressive decline in exercise as ambient temperature increases. However, the reasons for a diminished exercise performance in hot environment compared to the rest of ambient temperatures is still debated and it is considered to be multifactorial, as it will depend on the type of exercise, training status, motivation of the participants, acclimatization and/or hydration status.[8]

During the last century there has been a great effort from the scientific community in order to understand the complexity of hyperthermia-induced fatigue. It is considered that different physiological factors might limit maximal intensity exercise than submaximal intensity aerobic performance when exercising in the heat.[5] For maximal intensity exercise, cardiovascular mechanisms related to oxygen delivery are likely to limit aerobic performance in the heat.[6] High skin temperatures and the resulting elevation in skin blood flow are associated with impaired cardiac filling, reductions in end-diastolic volume and heart rate increases as an attempt to compensate a decreased stroke volume.[5] Whereas for submaximal exercise, it seems to be more complex and interaction between several physiological factors may be responsible for inducing premature fatigue during prolonged exercise in the heat.[7, 8] One of these physiological factors, a critically high level of body temperature ~40ºC, was proposed by Nielsen et al.[3] to be the main factor limiting endurance performance in hot environments. Thirteen trained participants, exercised at 60% peak oxygen uptake at an ambient temperature of 40ºC and 10% relative humidity for 9-12 consecutive days and observed that fatigue occurred when participants reached a core temperature of 39.7ºC despite large improvements in exercise performance (from 48 to 80 minutes). Six years later, Gonzalez-Alonso and colleagues,[9] observed similar results in seven trained cyclists who exercised at 60% maximal oxygen uptake in the heat (40ºC) until volitional exhaustion. Again, all participants fatigued at an identical level of hyperthermia (esophageal temperatures of 40.1-40.2ºC), regardless different initial temperatures. Authors from both studies concluded that a high body temperature, *per se*, was the main factor for exhaustion during exercise in heat stress. These studies formed the basis of the belief that high core temperature might be important for impairing exercise performance.

Temperature regulation mechanisms

Maintaining thermal balance in a hot environment is not only critical to preserving life and reducing heat illnesses; it is also essential in order to prevent decrements in athletic performance.[11] It is well known that more than 75% of the energy that is generated by skeletal muscle substrate oxidation is released as heat.[10] In order to promote heat loss, excess heat is transported from the core to the skin and then to the environment. Once the metabolic heat is transferred to the skin, there are various ways in which it can be lost to the environment, including radiation, conduction, convection and evaporation.[10] During rest in a thermoneutral environment, radiation accounts for approximate 60% of total heat loss, conduction and convection for 15% and evaporation for 25%. These percentages will change during exercise, where evaporation will be the main mechanism of heat loss.

According to the heat balance equation, when heat gain exceeds heat loss, body heat storage increases, elevating body temperature. During fixed-intensity (constant power) exercise, metabolic heat production is constant, and therefore, heat loss is limited only to autonomic responses.[12] Consequently, core body temperature theoretically rises until heat balance is achieved as indicated by a 'plateau' in core temperature observed in previous research.[13, 14] However, during fixed-intensity exercise in a hot environment, the heat balance is impossible to achieve; therefore, core temperature will rise linearly until exhaustion occurs. The inability to continue exercising in a hot environment is directly associated with the failure to achieve heat balance as heat exhaustion is accompanied by high core temperatures and an increased challenge for the cardiovascular system to simultaneously meet the demands for both the working musculature and temperature regulation.[12]

Aging: A risk factor for heat stress

The ability to physiologically maintain body core temperature during heat stress becomes compromised with age.[15] Individuals over the age of 60 years are the most vulnerable population during heat waves.[16] Adults in this age group experience greater thermal strain during passive heat exposures [17, 18] and this could be heightened when exercising in the heat.[19] Furthermore, age-related reductions in whole-body heat loss capacity are evident when exercising in hot environments.[20, 21] This progressive reduction in the thermoregulatory ability can be associated with reduced sweat gland outputs, decreased skin blood flow, smaller increase in cardiac output and/or less redistribution of blood flow from renal and splanchnic circulations.[22] Moreover, the problem can be exacerbated by the decreases in overall physical fitness and increases in body adiposity that may accompany aging, and experts have suggested that, in combination, these age-related changes in thermoregulatory and cardiovascular function can decrease the body's ability to maintain body core temperature at safe levels, especially during extended exposure to heat or to physical activity in the heat.[19] However, older adults up to the seventh decade of life and who are well trained, can safely complete the same relative workloads, comparing to moderately trained young men, without an increased risk of heat stress or heat stroke.[23]

Conversely, older adults show a decreased ability to sense and adapt to dehydration. In physiology studies in which dehydration was induced through heat exposure alone, through physical activity in the heat or through hypertonic saline infusion, healthy older individuals displayed lower subjective levels of thirst, decreased plasma volume and reduced water intake while dehydrated relative to younger counterparts.[19] Furthermore, recovery from dehydration is prolonged in older adults, which may exacerbate their risk of heat-related injuries during extended periods of heat exposure.

Strategies to reduce hyperthermia

Over the last decade, there has been an increasing interest in designing intervention strategies to reduce and/or delay increases in core temperature and therefore enhance exercise performance. This topic is, this year again, becoming relevant with such an important sport event as it is *Rio 2016 Olympics*, where it is expected to reach temperatures of up to 30ºC and 60% relative humidity. According to the review by Wendt and colleagues,[10] there are two main strategies that have been proven to be particularly effective in reducing health problems and performance decrements associated with hot environments: heat acclimatization and rehydration. In recent years, many other different strategies have been put in practice in order to prevent and/or delay increases in core temperature. Examples include ice-water immersion, ice-pack application, continual dousing with water combined with fanning,[24] ice slurry ingestion [25] or the use of compression garments [26] to name a few.

Compression garments.

Studies on compression garments have recently emerged although fundamental effects on thermoregulatory strain remain equivocal.[27] Claims from manufacturers include enhanced comfort perception,[28] increased muscle blood flow and/or enhanced lactate removal.[29] Further, recent developments in these garments have led to claims of thermoregulatory benefits attributed to increased heat dissipation as a result of improved sweat efficiency.[30] However, this remains a contentious issue, as there remains a lack of research supporting these statements.

While the use of lower body compression garments seems to be widely studied,[26, 28, 31-33] there is limited research regarding the effects of wearing upper body compression garments. It has been shown that when male athletes exercise at 55% and 75% of the maximal oxygen consumption in moderate warm conditions (25ºC and 50% relative humidity), the highest sweat rates occur on the central (upper and mid) and lower back.[34] As the evaporation of the sweat from the skin surface is the main mechanism to reduce heat storage during exercise, clothing designs that facilitate the heat dissipation in the upper body through compression may lead to lower body temperature increments and therefore delay the appearance of hyperthermia during exercise.

Figure 1. *The heat dissipating upper body compression garment used in the present doctoral thesis.*

AIM AND LAYOUT OF THE THESIS

The use of heat dissipating upper body compression garments is a novel strategy to reduce hyperthermia that has not been studied before. Following manufacturers' statements, the use of a heat dissipating upper body compression garment would enhance heat dissipation and lead to a reduced mean body temperature. If true, a hypothetically lower body temperature may allow athletes to enhance exercise performance, or delay the appearance of hyperthermia and subsequent heat illnesses in older adults. Thus, the aim of this thesis was, to investigate the validity of a heat dissipating upper body compression garment as a novel strategy to reduce increments in body temperature during exercise at different environmental conditions in healthy active population. The aim of each study has been summarized in table 1.

Study	Title and research aim
<u>*Study 1*</u> (Chapter 1):	**Heat dissipating upper body compression garment: Thermoregulatory, cardiovascular, and perceptual responses** *Research aim: The aim of the present study was to determine the effects of an upper body compression garment (UBCG) on thermoregulatory responses during cycling in a controlled laboratory thermoneutral environment (~23ºC). A secondary aim was to determine the cardiovascular and perceptual responses when wearing the garment.*
<u>*Study 2*</u> (Chapter 2):	**Impaired cardiorespiratory responses when wearing an upper body compression garment during recovery in a hot environment (40 ºC)** *Research aim: The aim of the present study was to investigate whether a heat dissipating UBCG would mitigate thermoregulatory strain better than a conventional non-CG control garment during cycling in a hot environment (40 ºC). A secondary aim was to determine whether wearing heat dissipating UBCG would aid in the acute recovery, lowering either thermoregulatory or cardiorespiratory strain.*
<u>*Study 3*</u> (Chapter 3):	**Increased thermoregulatory strain when wearing an upper body compression garment during moderate exercise in 66- year-old cyclists** *Research aim: The aim of the present study was to evaluate the effects of an UBCG on thermoregulatory responses in elderly trained cyclists in a temperate environment without constant airflow. A secondary aim was to assess UBCG effects on cardiorespiratory and perceptual responses during exercise.*
<u>*Study 4*</u> (Chapter 4):	**Running performance while wearing a heat dissipating compression garment in male recreational runners** *Research aim: The aim of this study was to analyze the physiological responses of a heat dissipating UBCG during a running performance test to exhaustion. A secondary aim was to examine the effects of UBCG during recovery after a high intensity exercise to exhaustion.*

References

1. Galloway SD, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. Med Sci Sports Exerc. 1997 Sep;29(9):1240-9. PubMed PMID: 9309637.

2. Lee FS, Scott EL. The action of temperature and humidity on the working power of muscles and on the sugar of the blood. American Journal of Physiology -- Legacy Content. 1916 1916-05-01 00:00:00;40(3):486-501.

3. Nielsen B, Hales JR, Strange S, Christensen NJ, Warberg J, Saltin B. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. J Physiol. 1993 Jan;460:467-85. PubMed PMID: 8487204. Pubmed Central PMCID: PMC1175224.

4. Parkin JM, Carey MF, Zhao S, Febbraio MA. Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise. J Appl Physiol (1985). 1999 Mar;86(3):902-8. PubMed PMID: 10066703.

5. Nybo L, Rasmussen P, Sawka MN. Performance in the heat-physiological factors of importance for hyperthermia-induced fatigue. Compr Physiol. 2014 Apr;4(2):657-89. PubMed PMID: 24715563.

6. Gonzalez-Alonso J, Calbet JA. Reductions in systemic and skeletal muscle blood flow and oxygen delivery limit maximal aerobic capacity in humans. Circulation. 2003 Feb 18;107(6):824-30. PubMed PMID: 12591751.

7. Nybo L. Cycling in the heat: performance perspectives and cerebral challenges. Scand J Med Sci Sports. 2010 Oct;20 Suppl 3:71-9. PubMed PMID: 21029193.

8. Nybo L. Brain temperature and exercise performance. Exp Physiol. 2012 Mar;97(3):333-9. PubMed PMID: 22125311.

9. Gonzalez-Alonso J, Teller C, Andersen SL, Jensen FB, Hyldig T, Nielsen B. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. J Appl Physiol (1985). 1999 Mar;86(3):1032-9. PubMed PMID: 10066720.

10. Wendt D, van Loon LJ, Lichtenbelt WD. Thermoregulation during exercise in the heat: strategies for maintaining health and performance. Sports Med. 2007;37(8):669-82. PubMed PMID: 17645370.

11. Davis JK, Bishop PA. Impact of clothing on exercise in the heat. Sports Med. 2013 Aug;43(8):695-706. PubMed PMID: 23620245.

12. Schlader ZJ, Raman A, Morton RH, Stannard SR, Mundel T. Exercise modality modulates body temperature regulation during exercise in uncompensable heat stress. Eur J Appl Physiol. 2011 May;111(5):757-66. PubMed PMID: 20978782.

13. Nielsen B, Nielsen M. Body temperature during work at different environmental temperatures. Acta Physiol Scand. 1962 Oct;56:120-9. PubMed PMID: 13938500.

14. Saltin B, Hermansen L. Esophageal, rectal, and muscle temperature during exercise. J Appl Physiol. 1966 Nov;21(6):1757-62. PubMed PMID: 5929300.

15. Inbar O, Morris N, Epstein Y, Gass G. Comparison of thermoregulatory responses to exercise in dry heat among prepubertal boys, young adults and older males. Exp Physiol. 2004 Nov;89(6):691-700. PubMed PMID: 15328309.

16. Rey G, Jougla E, Fouillet A, Pavillon G, Bessemoulin P, Frayssinet P, et al. The impact of major heat waves on all-cause and cause-specific mortality in France from 1971 to 2003. Int Arch Occup

Environ Health. 2007 Jul;80(7):615-26. PubMed PMID: 17468879. Pubmed Central PMCID: PMC2291483.

17. Dufour A, Candas V. Ageing and thermal responses during passive heat exposure: sweating and sensory aspects. Eur J Appl Physiol. 2007 May;100(1):19-26. PubMed PMID: 17242944.

18. Armstrong CG, Kenney WL. Effects of age and acclimation on responses to passive heat exposure. J Appl Physiol (1985). 1993 Nov;75(5):2162-7. PubMed PMID: 8307874.

19. Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O. Heat stress in older individuals and patients with common chronic diseases. CMAJ. 2010 Jul 13;182(10):1053-60. PubMed PMID: 19703915. Pubmed Central PMCID: PMC2900329.

20. Stapleton JM, Poirier MP, Flouris AD, Boulay P, Sigal RJ, Malcolm J, et al. Aging impairs heat loss, but when does it matter? J Appl Physiol (1985). 2015 Feb 1;118(3):299-309. PubMed PMID: 25505030. Pubmed Central PMCID: PMC4312844.

21. Larose J, Boulay P, Sigal RJ, Wright HE, Kenny GP. Age-related decrements in heat dissipation during physical activity occur as early as the age of 40. PLoS One. 2013;8(12):e83148. PubMed PMID: 24349447. Pubmed Central PMCID: PMC3861480.

22. Kenney WL, Munce TA. Invited review: aging and human temperature regulation. J Appl Physiol (1985). 2003 Dec;95(6):2598-603. PubMed PMID: 14600165.

23. Best S, Caillaud C, Thompson M. The effect of ageing and fitness on thermoregulatory response to high-intensity exercise. Scand J Med Sci Sports. 2012 Aug;22(4):e29-37. PubMed PMID: 22092378.

24. McDermott BP, Casa DJ, Ganio MS, Lopez RM, Yeargin SW, Armstrong LE, et al. Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. J Athl Train. 2009 Jan-Feb;44(1):84-93. PubMed PMID: 19180223. Pubmed Central PMCID: PMC2629045.

25. Ross ML, Garvican LA, Jeacocke NA, Laursen PB, Abbiss CR, Martin DT, et al. Novel precooling strategy enhances time trial cycling in the heat. Med Sci Sports Exerc. 2011 Jan;43(1):123-33. PubMed PMID: 20508537.

26. Goh SS, Laursen PB, Dascombe B, Nosaka K. Effect of lower body compression garments on submaximal and maximal running performance in cold (10 degrees C) and hot (32 degrees C) environments. Eur J Appl Physiol. 2011 May;111(5):819-26. PubMed PMID: 21046140.

27. MacRae BA, Laing RM, Niven BE, Cotter JD. Pressure and coverage effects of sporting compression garments on cardiovascular function, thermoregulatory function, and exercise performance. Eur J Appl Physiol. 2012 May;112(5):1783-95. PubMed PMID: 21901265.

28. Ali A, Creasy RH, Edge JA. Physiological effects of wearing graduated compression stockings during running. Eur J Appl Physiol. 2010 Aug;109(6):1017-25. PubMed PMID: 20354717.

29. Houghton LA, Dawson B, Maloney SK. Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. J Sci Med Sport. 2009 Mar;12(2):303-9. PubMed PMID: 18078787.

30. Website X-Bionic: https://www.x-bionic.com/.

31. Ali A, Caine MP, Snow BG. Graduated compression stockings: physiological and perceptual responses during and after exercise. J Sports Sci. 2007 Feb 15;25(4):413-9. PubMed PMID: 17365528.

32. Barwood MJ, Corbett J, Feeney J, Hannaford P, Henderson D, Jones I, et al. Compression garments: no enhancement of high-intensity exercise in hot radiant conditions. Int J Sports Physiol Perform. 2013 Sep;8(5):527-35. PubMed PMID: 23349313.

33. Chatard JC, Atlaoui D, Farjanel J, Louisy F, Rastel D, Guezennec CY. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. Eur J Appl Physiol. 2004 Dec;93(3):347-52. PubMed PMID: 15455235.

34. Smith CJ, Havenith G. Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. Eur J Appl Physiol. 2011 Jul;111(7):1391-404. PubMed PMID: 21153660.

RESUMEN

Ejercicio y estrés térmico

Las limitaciones en el rendimiento deportivo, han sido un tema de interés que ha fascinado a los humanos a lo largo de la historia. Existen varios factores que pueden influenciar la capacidad de un individuo para ejercitarse de forma prolongada, siendo uno de ellos la temperatura ambiente.[1] En 1916, Lee y Scott [2] fueron los primeros científicos en observar un agotamiento temprano durante la realización de ejercicio en un ambiente caluroso llevado a cabo en gatos. A pesar de que sus resultados no fueron concluyentes, fueron los primeros en observar que la realización de ejercicio en calor conducía a una prematura fatiga. Los siguientes estudios realizados en humanos, demostraron que el rendimiento aeróbico podría verse disminuido en ambientes calurosos en comparación con otros ambientes más templados.[1, 3, 4] Como ejemplo, Parkin et al.[4] investigaron los efectos que podían tener tres tipos de ambientes (3, 20 y 40ºC) en el rendimiento, durante la realización de ejercicio sub-máximo (70% del pico de consumo de oxígeno) hasta la extenuación. Los autores observaron una progresiva disminución del rendimiento a medida que la temperatura ambiental incrementaba. Sin embargo, todavía hoy, se sigue debatiendo las razones por las que la realización de ejercicio en calor disminuye el rendimiento deportivo. Se ha sugerido que podría ser una causa multifactorial y que dependería del tipo de ejercicio realizado, el estado de forma de los participantes, la motivación, la aclimatación y/o estado de hidratación.

Durante el siglo XX la comunidad científica ha venido realizando un gran esfuerzo con el objeto de conocer la complejidad de la fatiga inducida por hipertermia. Se cree que el ejercicio de máxima intensidad y el ejercicio sub-máximo pueden estar limitados por diferentes factores fisiológicos durante la realización de ejercicio en calor.[5] Durante el ejercicio de máxima intensidad, se sugiere que los mecanismos cardiovasculares, como el transporte de oxígeno, podrían limitar el rendimiento aeróbico en calor.[6] La altas temperaturas en la piel y el consiguiente incremento en el flujo sanguíneo están asociados a una disminución del volumen de llenado auricular asociado a una pérdida de presión vascular de retorno e incrementos en la frecuencia cardíaca, en un intento por compensar un descenso en el volumen sistólico.[5] Mientras que para el ejercicio sub-máximo, resulta más complejo, ya que la interacción de diferentes factores fisiológicos pueden ser los responsables de inducir una fatiga precoz durante la realización de ejercicio prolongado en calor.[7, 8] Uno de estos factores fisiológicos, un nivel elevado de la temperatura corporal cercana a los 40ºC, fue propuesto por Nielsen et al.[3] como factor limitante de rendimiento durante la realización de ejercicio en calor. Trece participantes entrenados, pedalearon al 60% del pico de consumo de oxígeno en un ambiente de 40ºC y 10% de humedad relativa durante 9-12 días consecutivos y observaron, que la fatiga ocurría cuando los participantes alcanzaban una temperatura interna de 39.7ºC a pesar de incrementar significativamente el rendimiento (de 48 a

80 minutos). Seis años después, González-Alonso y colaboradores,[9] observaron resultados similares en siete ciclistas entrenados que se ejercitaron al 60% del consumo máximo de oxígeno en calor (40ºC) hasta la extenuación. De nuevo, todos los participantes se agotaron a un nivel idéntico de hipertermia (temperaturas esofágicas entre 40.1-40.2ºC), a pesar de comenzar el protocolo con temperaturas iniciales diferentes. Los autores de ambos estudios concluyeron que una alta temperatura corporal, *per se*, fue el factor principal para que ocurriese la extenuación durante el ejercicio en calor. Estos estudios crearon las bases de que una elevada temperatura interna podría afectar el rendimiento deportivo.

Mecanismos de regulación de la temperatura

Mantener un balance térmico en un ambiente caluroso es crítico no solo para preservar la vida y reducir las complicaciones por exceso de calor, sino también para prevenir reducciones en el rendimiento deportivo.[11] Más del 75% de la energía que es generada por el músculo durante la oxidación de los sustratos es liberada en forma de calor.[10] Por lo tanto, nuestro organismo para perder el exceso de calor, debe transportarlo desde el interior del cuerpo a la piel y después liberarlo al ambiente. Una vez que el calor es transferido a la piel, existen varias vías por las que puede liberarse al ambiente, como la radiación, conducción, convección o evaporación.[10] Durante el reposo en un ambiente termoneutral, el cuerpo elimina un 60% de la pérdida total de calor por radiación, un 15% por conducción y convección, y un 25% por evaporación. Estos porcentajes cambian de manera significativa durante el ejercicio, donde la evaporación resulta ser el principal mecanismo de pérdida de calor.

De acuerdo con la ecuación del balance térmico, cuando el incremento de calor sobrepasa su posibilidad de pérdida, incrementa el almacenamiento de calor en el cuerpo, aumentando la temperatura interna. Durante el ejercicio de carga constante, la producción de calor metabólico es constante, por lo que la pérdida de calor está limitada únicamente a respuestas autónomas.[12] Y así teóricamente, la temperatura interna aumentaría hasta conseguir un balance térmico evidenciado por un "plateau" en la temperatura central, observado en estudios previos.[13, 14] Sin embargo, durante la realización de ejercicio de intensidad constante en un ambiente caluroso, resulta imposible mantener ese balance térmico, por lo que la temperatura interna incrementará linealmente hasta que el agotamiento aparezca. Esta incapacidad para continuar ejercitándose en calor está directamente asociada a la imposibilidad de mantener un equilibrio térmico, ya que el agotamiento por calor está acompañado por altas temperaturas internas y un gran desafío del sistema cardiovascular para mantener simultáneamente las demandas de la musculatura y el mantenimiento de la temperatura.[12]

Envejecimiento: Un factor de riesgo durante el estrés térmico

La habilidad de mantener fisiológicamente la temperatura corporal durante un estrés térmico se ve comprometida con la edad.[15] Los individuos por encima de los 60 años son la población más vulnerable durante las olas de calor.[16] Los adultos en este rango de edad experimentan un mayor estrés térmico durante la exposición pasiva al calor [17, 18] y este problema podría verse intensificado durante el ejercicio en calor.[19] Es más, las reducciones en la capacidad de pérdida de calor corporal relacionado con la edad son evidentes durante ejercicio en ambientes calurosos.[20, 21] Esta progresiva reducción en la habilidad termorreguladora podría estar relacionada con: una reducción en la producción de sudor de las glándulas sudoríparas, una disminución del flujo sanguíneo a la piel, una reducción del gasto cardiaco y/o una menor redistribución del flujo sanguíneo desde los órganos internos al resto de cuerpo.[22] Además, el problema puede agravarse con el deterioro del estado físico y los incrementos de grasa corporal que suelen acompañar al envejecimiento. Los expertos han sugerido que en combinación, estos cambios en las funciones termorreguladoras y cardiovasculares pueden disminuir la habilidad de nuestro cuerpo para mantener la temperatura corporal en un nivel seguro, especialmente durante largas exposiciones en ambientes calurosos o ejercicio en calor.[19] A pesar de ello, las personas mayores, hasta los 70 años de edad, que están bien entrenados, podrían completar de manera segura la misma relativa carga de trabajo en comparación a jóvenes moderadamente entrenados, sin un riesgo aumentado de padecer complicaciones por exceso de calor o un golpe de calor.[23]

Por otro lado, las personas mayores muestran una habilidad reducida para sentir y adaptarse a la deshidratación. En estudios fisiológicos en los que se indujo una deshidratación, ya fuera por exposición al calor, a través de actividad física en calor o una solución salina hipertónica, individuos mayores y sanos exhibieron menores niveles de sed, mayores descensos en el volumen plasmático y reducciones en la ingesta hídrica en comparación con sus homólogos más jóvenes.[19] Es más, la recuperación por deshidratación se prolonga de mayor manera en las personas mayores, lo que puede agravar los riesgos de sufrir complicaciones por exceso de calor durante periodos prolongados en calor.

Estrategias para reducir la hipertermia

Durante la última década, se han venido diseñando estrategias de intervención para reducir y/o retrasar incrementos en la temperatura central y, por lo tanto, incrementar el rendimiento deportivo. Estas estrategias están siendo relevantes de nuevo este año con un evento deportivo tan importante como las *Olimpiadas de Rio 2016*, donde se esperan temperaturas por encima de los 30ºC y un 60% de humedad relativa. De acuerdo con la revisión de Wendt y colaboradores,[10] existen dos estrategias principales que han resultado ser efectivas a la hora de reducir problemas de salud o disminuir el rendimiento en un ambiente caluroso: la aclimatación al calor y la rehidratación. En los últimos años, se han estudiado muchas otras estrategias con el fin de prevenir y/o retrasar incrementos en la temperatura central. Podemos encontrar baños en agua helada, aplicación de bolsas de hielo, una combinación de refrescarse con agua y viento,[24] la ingesta de granizados [25] o el uso de ropa compresiva [26] entre otros.

Ropa compresiva

En los últimos años, los estudios en relación al uso de la ropa compresiva han crecido de manera significativa, aunque los efectos en reducir el estrés termorregulador permanecen inciertos.[27] Los fabricantes aseguran que la ropa compresiva aumenta el confort,[28] incrementa el flujo sanguíneo muscular y/o ayuda en el aclaramiento del lactato.[29] Además, las recientes evoluciones en este tipo de ropa ha llevado a los fabricantes a asegurar que la ropa compresiva dispone de beneficios termorreguladores, incrementando la disipación de calor a través de una mejora en la eficiencia del sudor [30] (Figura 1). Sin embargo, existe polémica en relación a este último asunto, ya que hasta ahora no existen estudios que hayan respaldado estas afirmaciones.

Mientras que el uso de la ropa compresiva de miembro inferior ha sido ampliamente estudiado,[26, 28, 31-33] los estudios en relación al uso de ropa compresiva de miembro superior son limitados. Se ha demostrado que durante la realización de ejercicio de un atleta a una intensidad 55% y al 75% del consumo máximo de oxígeno en un ambiente templado (25ºC y 50% de humedad relativa), los mayores ratios de sudoración ocurren en la parte central (superior y media) y media de la espalda.[34] Dado que la evaporación del sudor desde la piel es el principal mecanismo para reducir la acumulación de calor durante el ejercicio, diseños de ropa que facilitaran la disipación del calor en el miembro superior a través de la compresión, podrían reducir los incrementos en la temperatura corporal y, por consiguiente, retrasar la aparición de la hipertermia durante el ejercicio.

Figura 1. *Ropa compresiva de disipación térmica utilizada en la presente tesis doctoral.*

OBJETIVO Y DISEÑO DE LA TESIS

El uso de la ropa compresiva de disipación térmica de miembro superior es una nueva estrategia para reducir la hipertermia que no ha sido estudiada anteriormente. Siguiendo las declaraciones de los fabricantes, el uso de este tipo de vestimentas podría incrementar la disipación térmica y reducir por lo tanto la temperatura corporal. De ser cierto, una hipotética menor temperatura corporal permitiría a los atletas mejorar su rendimiento, y también ayudaría a las personas mayores en el retraso de la aparición de la hipertermia y las posteriores complicaciones por exceso de calor. Por lo tanto, el objeto de esta presente tesis fue investigar la validez de un tipo de ropa compresiva de disipación térmica de miembro superior como estrategia para reducir los incrementos en la temperatura corporal durante ejercicio en diferentes condiciones ambientales realizado a población sana y activa. Cada objetivo de estudio se resume en la tabla 1.

Estudio	Título y objetivo del estudio
Estudio 1 (Capítulo 1):	**Heat dissipating upper body compression garment: Thermoregulatory, cardiovascular, and perceptual responses** *Objetivo: El objeto del presente estudio fue determinar los efectos de una ropa compresiva en las respuestas termorreguladoras durante la realización de ejercicio en cicloergómetro en un ambiente termoneutral (~23ºC). Un objetivo secundario fue determinar las respuestas cardiovasculares y perceptuales con el uso de esta vestimenta.*
Estudio 2 (Capítulo 2):	**Impaired cardiorespiratory responses when wearing an upper body compression garment during recovery in a hot environment (40 ºC)** *Objetivo: El objeto del presente estudio fue investigar si una ropa compresiva de disipación térmica mitigaría el estrés termorregulador de mejor manera que una ropa no compresiva (control) durante la realización de ejercicio en cicloergómetro en un ambiente caluroso (40ºC). Un objetivo secundario fue determinar si el uso de una ropa compresiva de disipación térmica ayudaría en la recuperación, reduciendo tanto el estrés termorregulador como el cardiorrespiratorio.*
Estudio 3 (Capítulo 3):	**Increased thermoregulatory strain when wearing an upper body compression garment during moderate exercise in 66- year-old cyclists** *Objetivo: El objetivo del presente estudio fue evaluar los efectos de una ropa compresiva en las respuestas termorreguladoras en ciclistas mayores entrenados en un ambiente templado sin flujo de aire. Un objetivo secundario fue evaluar los efectos cardiorrespiratorios y perceptuales durante el ejercicio.*
Estudio 4 (Capítulo 4):	**Running performance while wearing a heat dissipating compression garment in male recreational runners** *Objetivo: El objetivo del presente estudio fue analizar las respuestas fisiológicas de una ropa de disipación térmica durante un test de rendimiento de carrera hasta la extenuación. Un objetivo secundario fue examinar los efectos de la ropa compresiva durante la recuperación después de la realización de un ejercicio de alta intensidad hasta el agotamiento.*

Referencias

1. Galloway SD, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. Med Sci Sports Exerc. 1997 Sep;29(9):1240-9. PubMed PMID: 9309637.

2. Lee FS, Scott EL. The action of temperature and humidity on the working power of muscles and on the sugar of the blood. American Journal of Physiology -- Legacy Content. 1916 1916-05-01 00:00:00;40(3):486-501.

3. Nielsen B, Hales JR, Strange S, Christensen NJ, Warberg J, Saltin B. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. J Physiol. 1993 Jan;460:467-85. PubMed PMID: 8487204. Pubmed Central PMCID: PMC1175224.

4. Parkin JM, Carey MF, Zhao S, Febbraio MA. Effect of ambient temperature on human skeletal muscle metabolism during fatiguing submaximal exercise. J Appl Physiol (1985). 1999 Mar;86(3):902-8. PubMed PMID: 10066703.

5. Nybo L, Rasmussen P, Sawka MN. Performance in the heat-physiological factors of importance for hyperthermia-induced fatigue. Compr Physiol. 2014 Apr;4(2):657-89. PubMed PMID: 24715563.

6. Gonzalez-Alonso J, Calbet JA. Reductions in systemic and skeletal muscle blood flow and oxygen delivery limit maximal aerobic capacity in humans. Circulation. 2003 Feb 18;107(6):824-30. PubMed PMID: 12591751.

7. Nybo L. Cycling in the heat: performance perspectives and cerebral challenges. Scand J Med Sci Sports. 2010 Oct;20 Suppl 3:71-9. PubMed PMID: 21029193.

8. Nybo L. Brain temperature and exercise performance. Exp Physiol. 2012 Mar;97(3):333-9. PubMed PMID: 22125311.

9. Gonzalez-Alonso J, Teller C, Andersen SL, Jensen FB, Hyldig T, Nielsen B. Influence of body temperature on the development of fatigue during prolonged exercise in the heat. J Appl Physiol (1985). 1999 Mar;86(3):1032-9. PubMed PMID: 10066720.

10. Wendt D, van Loon LJ, Lichtenbelt WD. Thermoregulation during exercise in the heat: strategies for maintaining health and performance. Sports Med. 2007;37(8):669-82. PubMed PMID: 17645370.

11. Davis JK, Bishop PA. Impact of clothing on exercise in the heat. Sports Med. 2013 Aug;43(8):695-706. PubMed PMID: 23620245.

12. Schlader ZJ, Raman A, Morton RH, Stannard SR, Mundel T. Exercise modality modulates body temperature regulation during exercise in uncompensable heat stress. Eur J Appl Physiol. 2011 May;111(5):757-66. PubMed PMID: 20978782.

13. Nielsen B, Nielsen M. Body temperature during work at different environmental temperatures. Acta Physiol Scand. 1962 Oct;56:120-9. PubMed PMID: 13938500.

14. Saltin B, Hermansen L. Esophageal, rectal, and muscle temperature during exercise. J Appl Physiol. 1966 Nov;21(6):1757-62. PubMed PMID: 5929300.

15. Inbar O, Morris N, Epstein Y, Gass G. Comparison of thermoregulatory responses to exercise in dry heat among prepubertal boys, young adults and older males. Exp Physiol. 2004 Nov;89(6):691-700. PubMed PMID: 15328309.

16. Rey G, Jougla E, Fouillet A, Pavillon G, Bessemoulin P, Frayssinet P, et al. The impact of major heat waves on all-cause and cause-specific mortality in France from 1971 to 2003. Int Arch Occup

Environ Health. 2007 Jul;80(7):615-26. PubMed PMID: 17468879. Pubmed Central PMCID: PMC2291483.

17. Dufour A, Candas V. Ageing and thermal responses during passive heat exposure: sweating and sensory aspects. Eur J Appl Physiol. 2007 May;100(1):19-26. PubMed PMID: 17242944.

18. Armstrong CG, Kenney WL. Effects of age and acclimation on responses to passive heat exposure. J Appl Physiol (1985). 1993 Nov;75(5):2162-7. PubMed PMID: 8307874.

19. Kenny GP, Yardley J, Brown C, Sigal RJ, Jay O. Heat stress in older individuals and patients with common chronic diseases. CMAJ. 2010 Jul 13;182(10):1053-60. PubMed PMID: 19703915. Pubmed Central PMCID: PMC2900329.

20. Stapleton JM, Poirier MP, Flouris AD, Boulay P, Sigal RJ, Malcolm J, et al. Aging impairs heat loss, but when does it matter? J Appl Physiol (1985). 2015 Feb 1;118(3):299-309. PubMed PMID: 25505030. Pubmed Central PMCID: PMC4312844.

21. Larose J, Boulay P, Sigal RJ, Wright HE, Kenny GP. Age-related decrements in heat dissipation during physical activity occur as early as the age of 40. PLoS One. 2013;8(12):e83148. PubMed PMID: 24349447. Pubmed Central PMCID: PMC3861480.

22. Kenney WL, Munce TA. Invited review: aging and human temperature regulation. J Appl Physiol (1985). 2003 Dec;95(6):2598-603. PubMed PMID: 14600165.

23. Best S, Caillaud C, Thompson M. The effect of ageing and fitness on thermoregulatory response to high-intensity exercise. Scand J Med Sci Sports. 2012 Aug;22(4):e29-37. PubMed PMID: 22092378.

24. McDermott BP, Casa DJ, Ganio MS, Lopez RM, Yeargin SW, Armstrong LE, et al. Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. J Athl Train. 2009 Jan-Feb;44(1):84-93. PubMed PMID: 19180223. Pubmed Central PMCID: PMC2629045.

25. Ross ML, Garvican LA, Jeacocke NA, Laursen PB, Abbiss CR, Martin DT, et al. Novel precooling strategy enhances time trial cycling in the heat. Med Sci Sports Exerc. 2011 Jan;43(1):123-33. PubMed PMID: 20508537.

26. Goh SS, Laursen PB, Dascombe B, Nosaka K. Effect of lower body compression garments on submaximal and maximal running performance in cold (10 degrees C) and hot (32 degrees C) environments. Eur J Appl Physiol. 2011 May;111(5):819-26. PubMed PMID: 21046140.

27. MacRae BA, Laing RM, Niven BE, Cotter JD. Pressure and coverage effects of sporting compression garments on cardiovascular function, thermoregulatory function, and exercise performance. Eur J Appl Physiol. 2012 May;112(5):1783-95. PubMed PMID: 21901265.

28. Ali A, Creasy RH, Edge JA. Physiological effects of wearing graduated compression stockings during running. Eur J Appl Physiol. 2010 Aug;109(6):1017-25. PubMed PMID: 20354717.

29. Houghton LA, Dawson B, Maloney SK. Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. J Sci Med Sport. 2009 Mar;12(2):303-9. PubMed PMID: 18078787.

30. Website X-Bionic: https://www.x-bionic.com/.

31. Ali A, Caine MP, Snow BG. Graduated compression stockings: physiological and perceptual responses during and after exercise. J Sports Sci. 2007 Feb 15;25(4):413-9. PubMed PMID: 17365528.

32. Barwood MJ, Corbett J, Feeney J, Hannaford P, Henderson D, Jones I, et al. Compression garments: no enhancement of high-intensity exercise in hot radiant conditions. Int J Sports Physiol Perform. 2013 Sep;8(5):527-35. PubMed PMID: 23349313.

33. Chatard JC, Atlaoui D, Farjanel J, Louisy F, Rastel D, Guezennec CY. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. Eur J Appl Physiol. 2004 Dec;93(3):347-52. PubMed PMID: 15455235.

34. Smith CJ, Havenith G. Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. Eur J Appl Physiol. 2011 Jul;111(7):1391-404. PubMed PMID: 21153660.

ABBREVIATIONS

List of the most commonly used abbreviations.

Abbreviation	**Meaning**
A_D	Body surface area
CG	Compression garment
CON	Control
Hct	Hematocrit
HR	Heart rate
HR_{max}	Maximal heart rate
HS	Heat storage
LBCG	Lower body compression garment
PPO	Peak power output
RER	Respiratory exchange ratio
Rh	Relative humidity
RPE	Rating of perceived exertion
T_{body}	Body temperature
T_{core}	Core temperature
T_{rec}	Rectal temperature
T_{sk}	Skin temperature
TTE	Time to exhaustion
UBCG	Upper body compression garment
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2peak}$	Peak oxygen uptake
W_{loss}	Body weight loss

CHAPTER 1

Heat dissipating upper body compression garment: Thermoregulatory, cardiovascular, and perceptual responses *

* **Leoz-Abaurrea I**, Tam N, Aguado-Jiménez R. Heat dissipating upper body compression garment: Thermoregulatory, cardiovascular, and perceptual responses. Journal of Sport and Health Science. 2016 Jan 11.

Abstract

Purpose: The aim of the present study was to determine the effects of an upper body compression garment (UBCG) on thermoregulatory responses during cycling in a controlled laboratory thermoneutral environment (~23ºC). A secondary aim was to determine the cardiovascular and perceptual responses when wearing the garment.

Methods: Sixteen untrained participants, (age 21.3 ± 5.7 years, VO_{2peak} 50.88 ± 8.00 mL/min/kg, mean ± SD) performed two cycling trials in a thermoneutral environment (~23ºC) wearing either UBCG or Control (Con) garment. Testing consisted of a 5-min rest on a cycle ergometer, followed by 4 bouts of cycling for 14 min at ~50% VO_{2peak}, with 1-min rest between each bout. At the end of these bouts there was 10-min of passive recovery. During the entire protocol rectal temperature (T_{rec}), skin temperature (T_{skin}), mean body temperature (T_{body}) and heat storage (HS) were measured. Heart rate (HR), VO_2, pH, hematocrit (Hct), plasma electrolytes, weight loss (W_{loss}), and perceptual responses were also measured.

Results: There were no significant differences between garments for T_{skin}, HS, HR, VO_2, pH, Hct, plasma electrolyte concentration, W_{loss}, and perceptual responses during the trial. T_{rec} did not differ between garment conditions during rest, exercise, or recovery although a greater reduction in T_{rec} wearing UBCG (p = 0.01) was observed during recovery. Lower T_{body} during recovery was found when wearing UBCG (36.82 ± 0.3 ºC *vs.* 36.99 ± 0.24 ºC).

Conclusion: Wearing a UBCG did not benefit thermoregulatory, cardiovascular, and perceptual responses during exercise although it was found to lower T_{body} during recovery, which suggests that it could be used as a recovery tool after exercise.

Keywords: Body temperature; Compression garment; Cycling; Heat dissipation; Thermoregulation

1. Introduction

Studies on compression garments (CG) have recently emerged although fundamental effects on cardiovascular and thermoregulatory strain remain equivocal.[1] Claims from manufacturers of CG include improved performance, enhanced comfort perception,[2] increased muscle blood flow, and enhanced lactate removal [3] to name a few. Further, recent developments in these garments have led to claims of thermoregulatory benefits attributed to increased heat dissipation as a result of improved sweat efficiency. However, this remains a contentious issue, as there remains a lack of research supporting these statements.

Physiological effects of wearing lower body compression garments (LBCG) on thermoregulation and cardiovascular responses have been widely studied.[1-4] Goh et al.,[4] investigated the effect of LBCG on running performance (20 min at first ventilatory threshold (VT_1) followed by a run to exhaustion at v-VO_{2max}) in cold (10ºC) and hot (32ºC) environments. During the 10ºC trial lower limb skin temperature (T_{skin}) was significantly higher when wearing CG. However, no significant differences in rectal temperature (T_{rec}), oxygen consumption (VO_2), or heart rate (HR) were observed at cold and hot conditions. Thus, the researchers concluded that LBCG had no adverse effects on running performance. Further, MacRae et al.,[1] examined pressure and coverage effects of a full-body CG on exercise performance, cardiovascular, and thermoregulatory function during 60 min fixed load cycling at 65% VO_{2max} and a 6-km time trial in temperate conditions (24ºC, 60% rh). The full-body CG caused mild increases in thermoregulatory and cardiovascular strain (covered skin temperature and blood flow), without adversely affecting core body temperature (T_{core}) or arterial pressure.

Interestingly, only a few researchers have investigated the effects of wearing UBCG. Of these, Dascombe et al.,[5] investigated the effects of UBCG in elite flat-water kayakers on performance and physiological responses during a 6-step incremental test followed by a 4-min maximal performance test. Wearing a UBCG did not provide any significant physiological or performance benefits. Similarly, Sperlich et al.,[6] did not find any benefits of wearing UBCG on power output, physiological and perceptual responses in well trained cross country skiers and triathletes during three 3-min sessions of double-poling sprint. However, in these studies thermoregulatory effects were not measured. Thus, to the authors' best knowledge no study has investigated the thermoregulatory effects of a heat dissipating UBCG during exercise.

Hence, the aim of the present study was to determine the effects of a UBCG on thermoregulatory responses during cycling in a controlled laboratory thermoneutral environment (~23ºC). A secondary aim was to determine the cardiovascular and perceptual responses when wearing the garment. Following manufacturers' statements that consider that the use of a heat dissipating UBCG would enhance heat dissipation, the use of this garment will lead to a reduced mean body temperature (T_{body}). Nevertheless, based on the present literature, no positive thermoregulatory effects have been found wearing CGs. Thus, we hypothesize that the use of a UBCG will have no effect on cardiovascular responses during a 1-h lasting intermittent aerobic trial. We also hypothesize that perceptual responses will not differ between garment conditions during exercise.

2. Material and methods

2.1 Participants

Sixteen untrained participants, twelve males and four females recreational cyclists (age 21.3 ± 5.7 years, height 1.77 ± 0.08 m, body mass 73.3 ± 7.9 kg, body surface area 1.90 ± 0.14 m^2, and VO_{2peak} 50.88 ± 8.00 mL/min/kg, mean ± SD) volunteered to participate in this study. Participants were asked to refrain from alcohol, caffeine, and strenuous activity 24 h prior to testing. They were also requested to continue with normal dietary practices during the study. All participants were informed about all of the tests and possible risks involved and were provided a written informed consent form before testing. The study was approved by the Ethic Committee of the Public University of Navarre in conformity with the Declaration of Helsinki.

2.2 Clothing information

Two types of garments were used in the present study: 1) UBCG, a commercially available short sleeve UBCG made of 94% nylon, 4% elastane, 2% polypropylene that according to manufacturers it has the quality to dissipate the heat transporting the excess of sweat away and allowing it to evaporate while exercising; and 2) control garment (Con), a commercially available short sleeve non-UBCG made of natural fabric (100% cotton). Garments were individually fitted according to manufacturer´s guidelines. Volunteers wore identical shorts and sport shoes during testing period to reduce differences between trials not from the CG itself.

2.3 Study procedure

Participants reported to the laboratory on three occasions, separated by 2-7 days to allow rest between sessions. Experimental trials were performed at the same time of the day to minimize circadian variation. The female menstrual cycle was also taken into account to eliminate the influence of differences in hormonal status. As the females performed two identical trials, they acted as their own controls. More importantly, they were screened to perform the trial in either the luteal or follicular phase. Thus, if a female performed her first trial in the luteal phase, the second trial was also performed in the luteal phase. On the first visit to the laboratory, peak oxygen uptake (VO_{2peak}) of each participant was determined in a thermoneutral environment (20ºC—23ºC) using a continuous incremental test on a cycle ergometer (Ergoselect 200; Ergoline, Bitz, Germany). After a 5-min warm-up at 50 W, participants began cycling at 50 W with increments of 25 W/min. VO_{2peak} was defined as the plateau in oxygen uptake despite increasing work rate (W). The criteria for determining VO_{2peak} were that the respiratory exchange ratio (RER) was >1.1, HR was >95% of the participant’s age predicted maximum HR, or visible signs of exhaustion, such as breathlessness or the inability to maintain the required power output.

During the second and the third visit, participants performed a cycling trial with either the UBCG or the Con in a thermoneutral environment (~23ºC) (22.65

± 1.04 ºC, 59% ± 5% relative humidity (rh), and 2.5 m/s airflow) in a randomized, counterbalanced order. The cycling trial consisted of 5-min resting on a cycling ergometer followed by four bouts of cycling at a fixed load (~50% VO_{2peak}) for 14 min, with each bout separated with a minute rest. After exercise participants rested 10 min on the cycling ergometer (Figure 1). Post-5 and post 10 (or Recovery) were respectively determined as 5 and 10 min passive recovery.

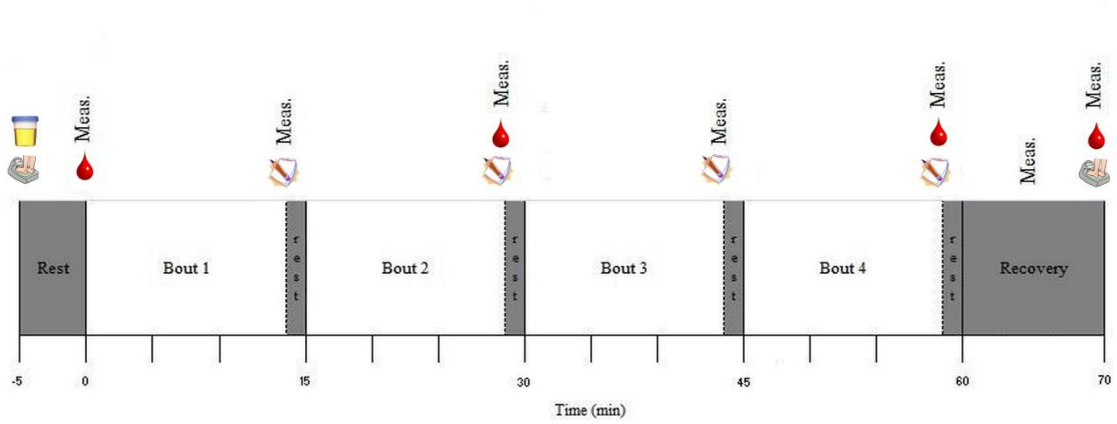

Figure 1. *Schematic illustration of experimental trial. Rest and recovery (in grey), bouts (1, 2, 3, and 4) (in white): 14-min cycling at a fixed load (50% of VO_{2peak}). Blood sampling (pH, hematocrit, and plasma electrolytes). Urine sampling (specific gravity). Nude body mass and clothes weighing. Perceptual responses. Measurements (Meas.): rectal temperature, mean skin temperature, oxygen consumption, and heart rate.*

2.4 Measurements

2.4.1 Hydration status, body mass, and garments weight

Participants voided their bladder before exercise and at the same time a urine sample was obtained to determine urine specific gravity using a refractometer (Hannah Instruments Inc., Woonsocket, RI, USA). Following this, nude body mass was measured before and after exercise using a medical scale (Seca, Toledo, OH, USA) accuracy ±0.05 kg. Each participant wiped himself dry with a towel to remove excess sweat. The garment mass was also measured before and after exercise using a precision balance (model 440-35N Kern Precision Balance, Balingen, Germany) accuracy ±0.01g. Subsequently, body weight loss (W_{loss}) was determined as the difference in nude body mass pre- and post-exercise (%). Sweat rate was calculated as the difference in W_{loss}/time (g/min). Sweat retention of the garment was determined as the difference in garments in pre- and post-exercise (g).

2.4.2 HR and respiratory gas exchange

HR was monitored continuously using an HR monitor (model FS2c Polar, Kempele, Finland). Oxygen consumption (VO_2) was measured breath by breath, using open circuit spirometry (Vacumed, CA, USA) at a sampling rate of 10 s. The gas analyzer was calibrated before each trial using a calibration gas mixture 15% O_2, 6% CO_2 (Praxair, Madrid, Spain) and the flowmeter was calibrated using a Jaeger 3L calibration syringe (Vacumed).

2.4.3 Rectal, skin, and mean body temperature

Rectal temperature (T_{rec}) was recorded using a sterile rectal thermistor (model 4600 precision thermistor thermometer, YSI, Yellow Springs, OH, USA) inserted 10 cm through the anal sphincter.[4] Four fast response skin temperature probes (model PS-2135, PASCO, Roseville, CA, USA) were placed using adhesive mylar foam covers (model PS-2525, PASCO) at four sites: chest, arm, thigh, and leg. Skin temperature (T_{sk}) data were continuously recorded with a data logger (NI USB-6259 BNC; National Instruments, Austin, TX USA) connected to a computer. A LabVIEW programme was used to record T_{sk} (LabWIEW, 2010, National Instruments). T_{sk} was calculated using the following formula:[7]

$$T_{sk} = 0.3 \times (T_{chest} + T_{arm}) + 0.2 \times (T_{thigh} + T_{leg}).$$

Mean body temperature was calculated using the following formula:[8]

$$T_{body} = 0.8 \times T_{rec} + 0.2 \times T_{sk}.$$

2.4.4 Heat storage (HS)

HS in body tissues was calculated [9] from the formula:

$$HS = 0.97\ BW_{pre}\ (T_{bpost} – T_{bpre})/(SA)\ (t)$$

Where 0.97 is the specific heat of tissue (W/h/kg/ºC), BW_{pre} is the pre-exercise body mass (kg), $(T_{bpost} - T_{bpre})$ represents the increase in mean body temperature during exercise (ºC), *SA* is the DuBois surface area (m^2) of the body [10] and *t* is the elapsed time (h).

2.4.5 Blood analysis

Capillary blood samples (95 µL) from the right hand index finger were sampled during the cycling trial, at rest, at the end of bout 2, at the end of bout 4, and at recovery (post 10). Blood samples were collected in heparinized capillaries and immediately analyzed in a medical Easystat® blood analyzer (Medica Corporation, Bedford, MA USA) for Concentration in plasma variables (pH, Hematocrit (Hct), Sodium (Na^+_{plasma}), and Potassium (K^+_{plasma})).

2.4.6 Perceptual data

The participant´s rating of perceived exertion (RPE) using a Borg 6-20 scale [11] and subjective sensation in respect of thermal sensation, shivering/sweating sensation and clothing wettedness sensation [12] were recorded at the end of each bout. Ratings of thermal sensation ranged from 1 (*very cold*) to 9 (*very hot*), shivering/sweating sensation ranged from 1 (*vigorously shivering*) to 7 (*heavily sweating*) and clothing wettedness sensation ranged from 1 (*dry*) to 4 (*wet*).

2.5 Statistical analyses

Data are presented as means ± SD. A repeated-measures (garment condition × time) analysis of variance (ANOVA,) SPSS version 17.0, Chicago, IL, USA was used to determine significant differences between the respective conditions (UBCG and Con). *Post-hoc* analysis was ducted with a Tukey's honest significant test to determine individual significant differences. Statistical significance was set as $p < 0.05$.

3. Results

3.1 Pre-exercise hydration condition, weight loss, and sweat rate

Euhydration before the trial was confirmed with a urine specific gravity <1.020 as indicated by National Collegiate Athletic Association.[13] No significant differences in W_{loss} (1.0% ± 0.2% *vs.* 1.2% ± 0.3%, UBCG and Con, respectively) or sweat rate (12.8 ± 3.2 g/min *vs.* 14.2 ± 5.0 g/min) were observed between garment conditions at the end of the trial.

3.2 Garments weight and sweat retention in garments.

UBCG was significantly heavier than Con before trial (198 ± 14 g *vs.* 135 ± 11 g; $p < 0.001$). Furthermore, at the end of the trial, significantly ($p = 0.04$) higher sweat retention in UBCG was found (6.47 ± 4.39 g *vs.* 3.71 ± 1.93 g). Nevertheless, when sweat retention in garments was normalized to sweat/g to garment mass, no significant differences were found between garment conditions ($p = 0.50$).

3.3 Thermoregulatory responses

Participants reached a similar T_{rec} (38.17 ± 0.40 ºC *vs.* 38.19 ± 0.37 ºC, UBCG and Con respectively) and T_{skin} (33.92 ± 0.94 ºC *vs.* 33.92 ± 1.28 ºC) at the end of exercise (Figures 2A and B). No difference in HS ($p = 0.54$) was found at the end of exercise between garment conditions. However a greater and significantly ($p = 0.03$) lower T_{body} (36.82 ± 0.30 ºC *vs.* 36.99 ± 0.24 ºC) ($p = 0.01$) rate of reduction in T_{rec} (-0.27 ± 0.10 ºC *vs.* -0.20 ± 0.10 ºC) and were found when wearing UBCG over the recovery period (Figs. 2C and 3).

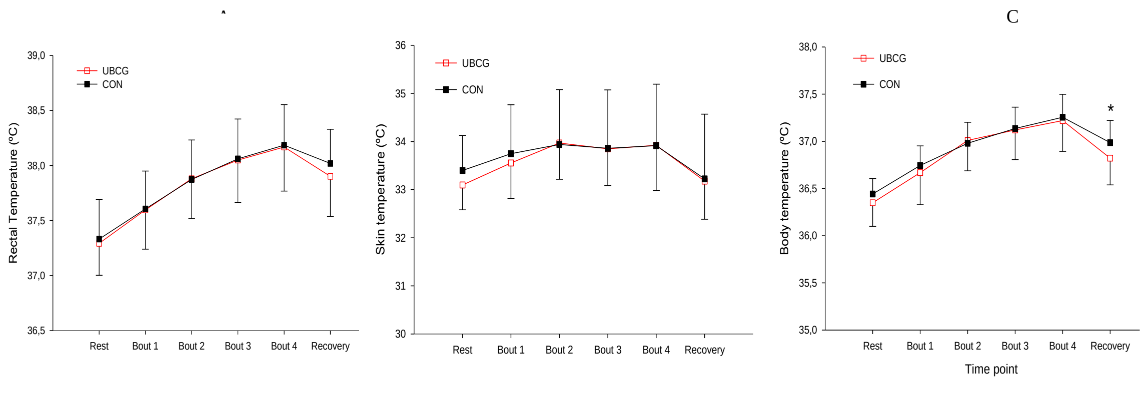

Figure 2. *Rectal (A), skin (B), and mean body temperature (C) during experimental trial. * Significantly different between garment conditions (p < 0.05). Values are presented as mean ± SD. Con = Control ; UBCG = Upper body compression garment.*

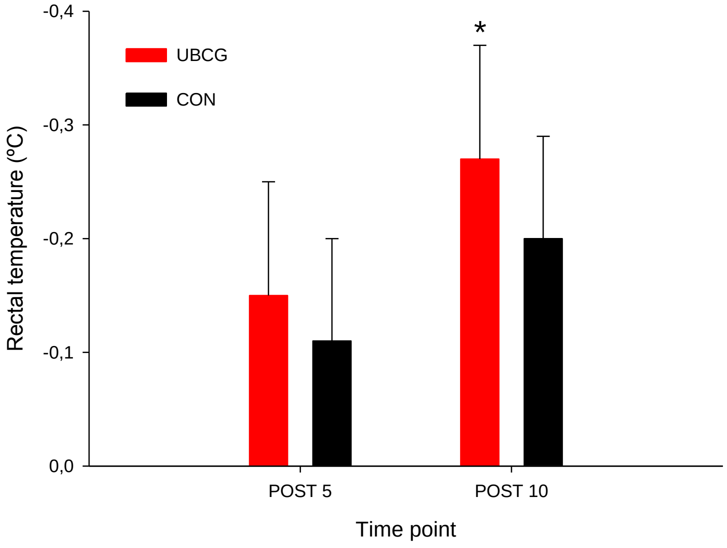

Figure 3. *Reduction in rectal temperature during recovery period. Post 5, reduction in rectal temperature after 5 min of passive recovery; post 10, reduction in rectal temperature after 10 min of passive recovery.* ***** *Significantly different between garment conditions (p < 0.05). Values are presented as mean ± SD. Con = Control ; UBCG = Upper body compression garment.*

3.4 Cardiorespiratory responses

Cardiorespiratory responses increased ($p < 0.001$) over time in both garment conditions from rest until the end of exercise although no differences in HR and VO_2 between garment conditions were observed over the trial (Figure 4).

3.5 Blood analysis

No significant differences in pH, Hct, Na^{+}_{plasma}, and K^{+}_{plasma} were observed between garment conditions during the trial (Table 1). Hct increased significantly from rest to the end of exercise in Con ($p = 0.04$) but not in UBCG ($p = 0.52$).

3.6 Perceptual responses

All perceptual responses increased ($p < 0.05$) significantly over time for both garment conditions. No significant differences in RPE, thermal sensation, shivering/sweating sensation, and clothing wettedness sensation were found over the trial despite different garment conditions.

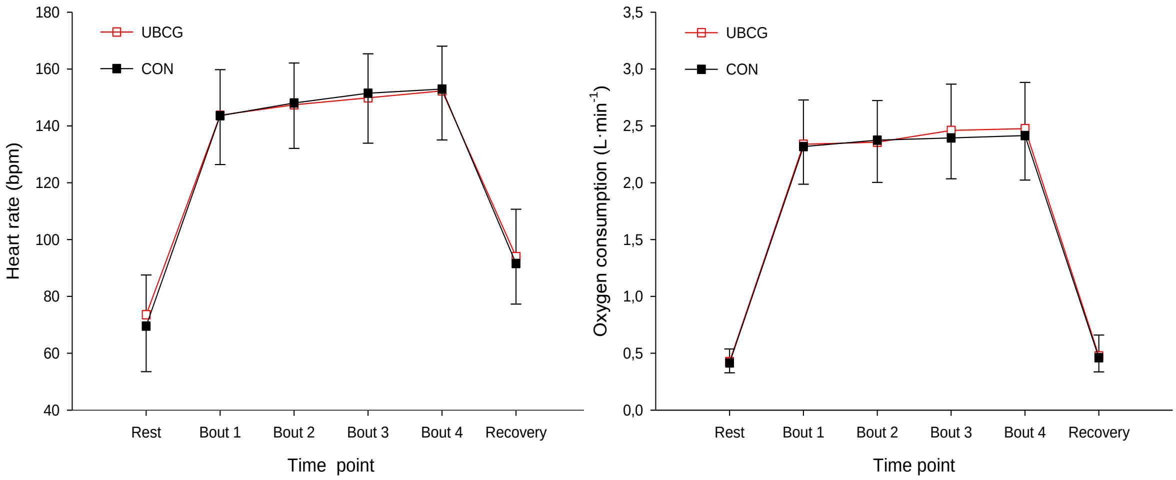

Figure 4. *Heart rate (A) and oxygen consumption (B) during experiental trial. Values are presented as mean ± SD. Con = Control ; UBCG = Upper body compression garment.*

Table 1. *Blood samples Absolute values for fingertip blood samples at rest, during exercise (Bouts 2 and 4) and recovery wearing upper body compression garment (UBCG) or control garment (Con) (mean ± SD).*

Variable	Group	Rest	Bout 2	Bout 4	Recovery
PH	UBCG	7.412 ± 0.034	7.390 ± 0.029	7.419 ± 0.023	7.406 ± 0.023
	CON	7.402 ± 0.015	7.390 ± 0.023	7.418 ± 0.028	7.397 ± 0.019
Hct (%)	UBCG	45 ± 3	48 ± 4	46 ± 4	47 ± 4
	CON	45 ± 3	47 ± 4	46 ± 3	46 ± 3
[Na^{+}_{plasma}] (mmol/L)	UBCG	144.5 ± 2.4	146.5 ± 2.2	148.6 ± 4.4	145.3 ± 2.4
	CON	143.7 ± 2.2	146.8 ± 3.7	147.7 ± 3.3	146.8 ± 3.0
K^{+}_{plasma} (mmol/L)	UBCG	5.0 ± 0.8	5.7 ± 0.9	6.1 ± 1.0	5.6 ± 1.4
	CON	4.6 ± 0.3	5.5 ± 0.8	6.0 ± 0.5	5.1 ± 0.6

** Significantly different from rest ($p < 0.05$).*

4. Discussion

The present study aimed to evaluate the effects of a heat dissipating UBCG during cycling at a submaximal intensity on thermoregulatory, cardiovascular, and perceptual effects. To our knowledge, no previous research studying physiological effects of wearing a UBCG during cycling in a thermoneutral environment have been performed. The main finding of the present study was that wearing a UBCG helped lowering T_{body} during the recovery process in a thermoneutral environment when compared to a similar control garment.

It was initially hypothesized that wearing a UBCG would not have an effect on thermoregulatory responses. Present hypothesis was consistent with previous research that had not found differences in thermoregulatory effects when wearing lower body compression garments in core temperature,[1, 3, 4] skin temperature [1, 14] and/or mean body temperature.[14] However, in the present study, a lower mean body temperature (Figure 2) and a greater rate of reduction in rectal temperature (Figure 3) were observed wearing the UBCG during the recovery period. Compression garments have been suggested as a possible method that could help in athletes recovery after high intensity training[15, 16] but no previous thermoregulatory benefits had been observed before. Furthermore, it has been shown that reducing core temperature prior to the onset of exercise increases the body´s ability to store endogenous and exogenous heat and therefore improves exercise performance,[17] consequently a lower mean body temperature in the recovery process could probably be beneficial in the continuation of the exercise after a short term recovery period. Conversely, Goh et al.[4] and Houghton et al.[3] did not find significant differences in core temperature when wearing compression garments, they did however observe a significant higher skin temperature at 10ºC and 17ºC, respectively. Both authors suggested that higher skin temperature could be due to the insulation effect of the garments that reduced air permeability. In the present study volunteers received a constant airflow (2.5 m/s) towards the chest that may have allowed a better permeability of the air in the garments.

Researchers studying thermoregulatory effects between synthetic or natural fabrics have not found differences in exercising rectal temperature in different ambient temperatures.[18] Exercising at a submaximal intensity in a thermoneutral environment neither the compression exerted on the skin nor the synthetic material were able to dissipate the heat better than a control garment made of natural fabrics. If the latter two elements (pressure and material) were not able to reduce mean body temperature during exercise another reason regarding greater reduction in rectal temperature during recovery must exist. Perhaps the greater contact of the garment to the skin together with the constant airflow could have transferred the heat better from the body to the ambient in the UBCG condition.

HR during the trial did not differ between the two conditions (Figure 4). This is consistent with previous research that did not find significant differences in HR wearing either compression garments or non-compression garments when exercising in a thermoneutral environment.[2, 4-6, 19, 20] Changes in HR between compression garments or non-compression garments during exercise have been shown to be similar even during cycling,[20, 21] running[2, 19, 22] kayaking,[5] or skiing.[6] During the recovery period, no significant reductions in HR between garment conditions have been recorded in previous studies.[19, 23] The findings from this study suggest that the use of compression garments during exercise or passive recovery in thermoneutral environments do not help in mitigating cardiovascular strain better than a non-compression garment.

Bringard et al.[22] reported lower aerobic energy cost when wearing compression tights at a submaximal exercise intensity (12 km/h). The authors suggested that wearing compression tights during running exercise could enhance overall circulation (venous blood flow) and decrease muscle oscillations to promote a lower energy cost. The same authors [24] evaluated the effects of compression tights on calf muscle oxygenation and venous pooling at resting conditions using a near-infrared spectroscopy (NIRS) and reported positive effects wearing them. However in the present study no changes in VO_2 during exercise were observed wearing UBCG. Pressure exerted on the upper limb (non-exercising limb) during cycling could have not achieved these expected results as reported Bringard et al.[22] when wearing LBCG. The present results are consistent with the recent findings by Dascombe et al.[5] and Sperlich et al.[6] who did not observe differences in oxygenation measures (NIRS and VO_2) when evaluated the effects of a UBCG on intermittent exercise. Hence, we conclude that wearing UBCG did not lower VO_2 values that could have increased blood flow during cycling at a submaximal intensity in a thermoneutral environment. Although, the present study did not measure the level of pressure exerted on the compressed limbs according to the present results we cannot support the idea that wearing UBCG could promote a lower energy cost lowering VO_2 values when exercising at moderate intensities.

Several authors have concluded that dehydration increases heat storage during exercise because dry heat loss is reduced.[25, 26] In the present study dehydration (W_{loss}) was only 1.0%-1.2% and did not differ between garment conditions. Moreover, plasma volume decreases when a person is severely dehydrated [27] and dehydration of 2% of body weight could lead to an increase in core temperature and cardiovascular strain.[28] Wearing UBCG did not ($p = 0.52$) increase Hct significantly over time whereas wearing the CON garment did ($p = 0.04$). Pressure exerted on the skin is known to produce an inhibitory effect on sweating rate.[29] Therefore, pressure exerted by UBCG on the skin may have reduced sweat rate, limiting the amount of sweat that left from the body to the skin and preventing participants from severe dehydration. Nevertheless, in this study no differences in Hct, Na^{+}_{plasma}, K^{+}_{plasma}, W_{loss}, or sweat rate were observed at the end of exercise (Table 1), therefore further studies of exercise lasting >1 h are needed to confirm the effects of UBCG on dehydration.

Despite participants having a previous knowledge about the possible benefits of wearing UBCG (they were not blinded to the garment condition), no differences in perceptual responses were observed. The possibility that the garment could have a positive psychological effect on participants did not interfere in perceptual responses. Clothing wettedness and shivering/sweating sensation did not differ between garment conditions. Cotton has shown greater water absorption, which has been consistently shown for natural fabrics compared to synthetic fabrics.[30, 31] Paradoxically greater sweat retention was observed in the UBCG after the trial probably due to a greater weight of the garment that accumulated bigger amounts of sweat. Nevertheless, differences did not exist when normalized to sweat/g to garment mass. As well as thermoregulatory and cardiorespiratory responses were not significantly different between two conditions at the end of exercise, thermal sensation and RPE also did not differ between garment conditions which means that during exercise while physiological differences remained similar between garments, psychological responses remained unaltered.

5. Conclusion

The results of this study appear to demonstrate the efficacy of wearing a heat dissipating UBCG during recovery process, which suggests that it might be a useful thermoregulatory tool after exercise. The use of a UBCG may be beneficial for intermittent exercise-based sports where there is a player rotation system such as, volleyball, handball, futsal; or individual sports with resting periods throughout the game (tennis).

Acknowledgments

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Authors' Contributions

ILA participated in the design of the manuscript, carried out data collection, performed the statistical analysis and drafted the manuscript; NT helped to draft the manuscript and language editing; RAJ conceived of the study, and participated in its design and coordination and helped to draft the manuscript.

Competing Interests

None of the authors declare competing financial interests.

References

1. MacRae BA, Laing RM, Niven BE, Cotter JD. Pressure and coverage effects of sporting compression garments on cardiovascular function, thermoregulatory function, and exercise performance. Eur J Appl Physiol. 2012 May;112(5):1783-95. PubMed PMID: 21901265.

2. Ali A, Creasy RH, Edge JA. Physiological effects of wearing graduated compression stockings during running. Eur J Appl Physiol. 2010 Aug;109(6):1017-25. PubMed PMID: 20354717.

3. Houghton LA, Dawson B, Maloney SK. Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. J Sci Med Sport. 2009 Mar;12(2):303-9. PubMed PMID: 18078787.

4. Goh SS, Laursen PB, Dascombe B, Nosaka K. Effect of lower body compression garments on submaximal and maximal running performance in cold (10 degrees C) and hot (32 degrees C) environments. Eur J Appl Physiol. 2011 May;111(5):819-26. PubMed PMID: 21046140.

5. Dascombe B, Laursen P, Nosaka K, Polglaze T. No effect of upper body compression garments in elite flat-water kayakers. Eur J Sport Sci. 2013;13(4):341-9. PubMed PMID: 23834538.

6. Sperlich B, Born DP, Zinner C, Hauser A, Holmberg HC. Does upper-body compression improve 3 x 3-min double-poling sprint performance? Int J Sports Physiol Perform. 2014 Jan;9(1):48-57. PubMed PMID: 23881333.

7. Ramanathan NL. A New Weighting System for Mean Surface Temperature of the Human Body. J Appl Physiol. 1964 May;19:531-3. PubMed PMID: 14173555.

8. Colin J, Timbal J, Houdas Y, Boutelie.C, Guieu JD. Computation of Mean Body Temperature from Rectal and Skin Temperatures. J Appl Physiol. 1971;31(3):484-&. PubMed PMID: WOS:A1971K371800027. English.

9. Mitchell JW, Nadel ER, Stolwijk JA. Respiratory Weight Losses during Exercise. J Appl Physiol. 1972;32(4):474-&. PubMed PMID: WOS:A1972M122600007. English.

10. Du Bois D, Du Bois E. A formula to estimate the approximate surface area if height and weight be known. 1916. Nutrition (Burbank, Los Angeles County, Calif). 1989;5(5):303.

11. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377-81. PubMed PMID: 7154893.

12. Ha M, Tokura H, Tanaka Y, Holmer I. Effects of two kinds of underwear on thermophysiological responses and clothing microclimate during 30 min walking and 60 min recovery in the cold. Appl Human Sci. 1996;15(1):33-9.

13. Volpe SL, Poule KA, Bland EG. Estimation of prepractice hydration status of National Collegiate Athletic Association Division I athletes. Journal of athletic training. 2009 Nov-Dec;44(6):624-9. PubMed PMID: 19911089. Pubmed Central PMCID: 2775364.

14. Barwood MJ, Corbett J, Feeney J, Hannaford P, Henderson D, Jones I, et al. Compression garments: no enhancement of high-intensity exercise in hot radiant conditions. Int J Sports Physiol Perform. 2013 Sep;8(5):527-35. PubMed PMID: 23349313.

15. Davies V, Thompson KG, Cooper SM. The effects of compression garments on recovery. J Strength Cond Res. 2009 Sep;23(6):1786-94. PubMed PMID: 19675482.

16. Kraemer WJ, Flanagan SD, Comstock BA, Fragala MS, Earp JE, Dunn-Lewis C, et al. Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. J Strength Cond Res. 2010 Mar;24(3):804-14. PubMed PMID: 20195085.

17. Ross M, Abbiss C, Laursen P, Martin D, Burke L. Precooling methods and their effects on athletic performance : a systematic review and practical applications. Sports Med. 2013 Mar;43(3):207-25. PubMed PMID: 23329610.

18. Davis JK, Bishop PA. Impact of clothing on exercise in the heat. Sports Med. 2013 Aug;43(8):695-706. PubMed PMID: 23620245.

19. Duffield R, Edge J, Merrells R, Hawke E, Barnes M, Simcock D, et al. The effects of compression garments on intermittent exercise performance and recovery on consecutive days. Int J Sports Physiol Perform. 2008 Dec;3(4):454-68. PubMed PMID: 19223671.

20. Scanlan AT, Dascombe BJ, Reaburn PR, Osborne M. The effects of wearing lower-body compression garments during endurance cycling. Int J Sports Physiol Perform. 2008 Dec;3(4):424-38. PubMed PMID: 19223669.

21. Chatard JC, Atlaoui D, Farjanel J, Louisy F, Rastel D, Guezennec CY. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. Eur J Appl Physiol. 2004 Dec;93(3):347-52. PubMed PMID: 15455235.

22. Bringard A, Perrey S, Belluye N. Aerobic energy cost and sensation responses during submaximal running exercise--positive effects of wearing compression tights. Int J Sports Med. 2006 May;27(5):373-8. PubMed PMID: 16729379.

23. Duffield R, Cannon J, King M. The effects of compression garments on recovery of muscle performance following high-intensity sprint and plyometric exercise. J Sci Med Sport. 2010 Jan;13(1):136-40. PubMed PMID: 19131276.

24. Bringard A, Denis R, Belluye N, Perrey S. Effects of compression tights on calf muscle oxygenation and venous pooling during quiet resting in supine and standing positions. J Sports Med Phys Fitness. 2006 Dec;46(4):548-54. PubMed PMID: 17119519.

25. Gonzalez-Alonso J, Mora-Rodriguez R, Below PR, Coyle EF. Dehydration reduces cardiac output and increases systemic and cutaneous vascular resistance during exercise. J Appl Physiol (1985). 1995 Nov;79(5):1487-96. PubMed PMID: 8594004.

26. Montain SJ, Coyle EF. Fluid ingestion during exercise increases skin blood flow independent of increases in blood volume. J Appl Physiol (1985). 1992 Sep;73(3):903-10. PubMed PMID: 1400054.

27. Dill DB, Costill DL. Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. J Appl Physiol. 1974 Aug;37(2):247-8. PubMed PMID: 4850854.

28. Armstrong LE, Maresh CM, Gabaree CV, Hoffman JR, Kavouras SA, Kenefick RW, et al. Thermal and circulatory responses during exercise: effects of hypohydration, dehydration, and water intake. J Appl Physiol (1985). 1997 Jun;82(6):2028-35. PubMed PMID: 9173973.

29. Ogawa T, Asayama M, Ito M, Yoshida K. Significance of skin pressure in body heat balance. Jpn J Physiol. 1979;29(6):805-16. PubMed PMID: 541903.

30. Gavin TP, Babington JP, Harms CA, Ardelt ME, Tanner DA, Stager JM. Clothing fabric does not affect thermoregulation during exercise in moderate heat. Med Sci Sports Exerc. 2001 Dec;33(12):2124-30. PubMed PMID: 11740309.

31. Brazaitis M, Kamandulis S, Skurvydas A, Daniuseviciute L. The effect of two kinds of T-shirts on physiological and psychological thermal responses during exercise and recovery. Appl Ergon. 2010 Dec;42(1):46-51. PubMed PMID: 20427033.

CHAPTER 2

Impaired cardiorespiratory responses when wearing an upper body compression garment during recovery in a hot environment (40 ºC) *

* **Leoz-Abaurrea I**, Tam N, Aguado-Jimenez R. Impaired cardiorespiratory responses when wearing an upper body compression garment during recovery in a hot environment (40 ºC). J Sports Med Phys Fitness. 2015 Mar 18.

Abstract

Background: Previous studies have not investigated the effects of a heat dissipating upper body compression garment (UBCG) during cycling in a hot environment. The present study examined the effects of a heat dissipating UBCG on thermoregulatory, cardiorespiratory and perceptual responses (thermal sensation and exertion scales), during cycling at a fixed workload (~50% VO_{2peak}) and during active recovery (~25% VO_{2peak}).

Methods: Thirteen untrained males (mean±SD; age 21±6 years, VO_{2peak} 53.7±5.0 $ml \cdot kg^{-1} \cdot min^{-1}$) completed two randomized cycling trials consisting of a 5 min rest on a cycling ergometer, followed by 4 bouts of 14 min at a fixed load + 1 min active recovery. Followed further by 10 min of active recovery. Testing occurred in a hot environment (~40±0.4 ºC, 35±2 % relative humidity, ~2.5 $m \cdot s^{-1}$ air velocity) and volunteers wore either a UBCG or non-UBCG (CON).

Results: Wearing UBCG resulted in significantly smaller reduction in heart rate (31±11 bpm *vs*. 46±15 bpm) and higher VO_2 and VCO_2 values ($P<0.05$) during 10 min recovery period. No differences in rectal, skin and body temperature were observed during the trial between garment conditions. Clothing wetness sensation remained significantly higher wearing CON ($P<0.05$) during exercise although no significant differences in weight loss or in sweat rate were observed.

Conclusions: These results suggest that wearing heat dissipating UBCG had no thermoregulatory benefits during exercise and it had impaired cardiorespiratory responses during active recovery when exercising in a hot environment.

Keywords: Hot temperature - Body temperature regulation - Exercise.

CHAPTER 3

Increased thermoregulatory strain when wearing an upper body compression garment during moderate exercise in 66- year-old cyclists *

* **Leoz-Abaurrea I**, Izquierdo M, González-Izal M, Aguado-Jiménez R. Increased thermoregulatory strain when wearing an upper body compression garment during moderate exercise in 66- year-old cyclists. J Aging Phys Act. 2016 Apr 11. Under review.

Abstract

The aim of this study was to evaluate the effects of an upper body compression garment (UBCG) on thermoregulatory, cardiorespiratory and perceptual responses during cycling in a temperate environment in active elderly sportsmen. Twelve cyclists aged 66±2 years performed an intermittent 1-h cycling-trial at 50% of the peak power output followed by 10 min of passive recovery at 25ºC. Participants were provided with either commercially available UBCG or control garment in a randomized order. UBCG increased thermoregulatory strain during exercise, as indicated by a significantly higher core temperature (p=.04), body temperature (p=.01) and thermal sensation (p=.02). Ratings of perceived exertion were significantly lower (p=.02) in the UBCG condition during the first half of the trial, although differences ultimately disappeared (p>.05). These results suggest that the use of UBCG in the active elderly population during exercise should be limited, considering that they may accelerate the appearance of hyperthermia in temperate environments.

Keywords: Exercise, older adult, core temperature, cycling, thermal sensation

1. Introduction

Individuals over the age of 60 years are the most vulnerable population during heat waves (Rey et al., 2007). Adults in this age group experience greater thermal strain during passive heat exposures (Armstrong & Kenney, 1993; Dufour & Candas, 2007) and this could be heightened when exercising in the heat (Kenny, Yardley, Brown, Sigal, & Jay, 2010). Furthermore, age-related reductions in whole-body heat loss capacity are evident when exercising in hot environments (Larose, Boulay, Sigal, Wright, & Kenny, 2013; Stapleton et al., 2015). This progressive reduction in the thermoregulatory ability can be associated with reduced sweat gland outputs, decreased skin blood flow, smaller increase in cardiac output and/or less redistribution of blood flow from renal and splanchnic circulations (Kenney & Munce, 2003).

Since an elevated level of body temperature (T_{body}) has been suggested to be the main factor limiting endurance in hot environments (Gonzalez-Alonso, Teller, et al., 1999), in recent years, many strategies have been put in practice in order to prevent or delay increases in core temperature (T_{core}). Examples include ice-water immersion, ice-pack application or continual dousing with water combined with fanning (McDermott et al., 2009) to name a few. Studies on compression garments (CG) have recently emerged although fundamental effects on thermoregulatory strain remain equivocal (MacRae, Laing, Niven, & Cotter, 2012). Claims from manufacturers include enhanced comfort perception (Ali, Creasy, & Edge, 2010), increased muscle blood flow and/or enhanced lactate removal (Houghton, Dawson, & Maloney, 2009). Further, recent developments in these garments have led to claims of thermoregulatory benefits attributed to increased heat dissipation as a result of improved sweat efficiency. However, this remains a contentious issue, as there remains a lack of research supporting these statements.

While the use of lower body compression garments seems to be widely studied (Ali, Caine, & Snow, 2007; Ali et al., 2010; Barwood et al., 2013; Chatard et al., 2004; Goh, Laursen, Dascombe, & Nosaka, 2011), there is limited research regarding the effects of wearing upper body compression garments (UBCG). It has been shown that when male athletes exercise at 55% and 75% of the maximal oxygen consumption ($\dot{V}O_{2max}$) in moderate warm conditions (25 ºC and 50% relative humidity), the highest sweat rates occur on the central (upper and mid) and lower back (Smith & Havenith, 2011). As the evaporation of the sweat from the skin surface is the main mechanism to reduce heat storage during exercise, clothing designs that facilitate the heat dissipation in the upper body through compression may lead to lower T_{body} increments and therefore delay the appearance of hyperthermia during exercise. Previous research studying the effects of the same UBCG in young (21 years) participants did not observe any thermoregulatory response differences during exercise in thermoneutral (Leoz-Abaurrea, Tam, & Aguado-Jiménez, 2016) or hot (Leoz-Abaurrea, Tam, & Aguado-Jimenez, 2015) environments. However, in those studies, the presence of a constant fan during the protocol could have mitigated potential UBCG effects. Hence, the aim of the present study was to evaluate the effects of an UBCG on thermoregulatory responses in elderly trained cyclists in a temperate environment without constant airflow. A secondary aim was to assess UBCG effects on cardiorespiratory and perceptual responses during exercise. It was hypothesized that the use of UBCG would not have any effect on thermoregulatory responses during cycling at a moderate intensity in a temperate environment. We also hypothesized that cardiorespiratory and perceptual responses would not differ between garment conditions during exercise.

2. Methods

Participants

Twelve elderly trained cyclists volunteered to participate in the study. Descriptive statistics of physical characteristics of the participants are presented in Table 1. No cases of cardiovascular or metabolic disease were present and no participants took any medications. Participants had trained an average of 6,200 ± 3,500 km·year^{-1} for at least 20 years. The Ethics committee of the Public University of Navarre approved this study, which was conducted in accordance with the principles of the Declaration of Helsinki. Before participation, cyclists completed the SF-36 health survey to rule out any injuries or medical conditions. Participants were informed about possible risks of the study and provided written consent before testing. All experimental trials were performed during the months of October and November 2015. Participants were asked to refrain from heavy exercise and to abstain from alcohol and caffeine ingestion in the 24 h before testing. Participants were also requested to drink 500 ml of water the night before and 2 h before the tests to ensure that the tests began from a euhydrated state. All tests were performed at the same time of the day to minimize circadian variations.

	n	Age (year)	Weight (kg)	Height (cm)	A_D (m^2)	Body fat (%)	$\dot{V}O_{2max}$ (ml·kg^{-1}·ml^{-1})	PPO (W)
Older adults	12	66 ± 2	77.9 ± 8.2	172 ± 6	1.91 ± 0.11	21 ± 4	33.0 ± 5.0	168 ± 36

Table 1. *Physical characteristics of older adults*
Abbreviations: A_D, body surface area; $\dot{V}O_{2max}$, maximal oxygen consumption; PPO, peak power output.

Experimental design

All participants undertook two experimental sessions, separated at least by 72 hours to allow rest. An Astrand-Rhyming cycle ergometer test was performed during the first visit to predict maximal oxygen consumption ($\dot{V}O_{2max}$). This test assumes a linear relationship between oxygen consumption ($\dot{V}O_2$) and heart rate (HR). Each subject tested on a cycle ergometer (Ergoselect 200, Ergoline, Bitz, Germany) at a constant pace for 6 minutes at a workload exceeding 125 beats per minute (bpm). If the participant´s pulse changed more than ± 5 bpm, the test continued in 1-minute increments until a steady state was obtained. When the participants did not reach a minimum of 125 bpm, the workload was increased in 25-watt (W) and maintained for another 6 min until the criteria was met. Participant´s HRs never exceeded 170 bpm during the test. An age-corrected factor was used to account for the decrease in maximal heart rate (HR_{max}) with age.

Peak power output (PPO) was estimated by having subjects cycled at two submaximal intensities (100 W and 125 W, respectively) for 5 minutes in each load. Participants´ HR during the last 15 seconds was recorded. PPO was estimated by a linear regression of the two submaximal workloads and the age predicted HR_{max} (220 - age).

Following a short period of passive sitting recovery (10 min), participants performed a 1-h cycling trial wearing either UBCG or control garment (CON) at 25 ± 1 ºC and 66 ± 4 relative humidity in a randomized order. The cycling trial consisted of 4 bouts at a fixed load (50% PPO) for 14 min, with each separated with a minute rest. Participants then rested for 10 min on the cycling ergometer. Garment information has been described before (Leoz-Abaurrea et al., 2015; Leoz-Abaurrea et al., 2016). During the second visit, the same procedure was followed to allow comparison between garments.

Measurements

Hydration status, body mass and sweat rate

Urine samples were obtained to determine urine specific gravity using a refractometer (Hannah Instruments Inc., Woonsocket, RI, US). Additionally, nude body mass was measured before and after exercise using a medical scale (Seca, Toledo, OH, US) and accuracy of ± 0.05 kg. Each participant first wiped himself dry with a towel to remove excess sweat. Body fat percentage was assessed using a Multi frequency segmental body composition monitor (Tanita MC-980, Arlington Heights, IL, US). Body weight loss (W_{loss}) was determined as the difference in nude body mass pre- and post-exercise (%). Sweat rate was calculated as the difference in W_{loss}/time (g/min).

Heart rate, respiratory gas exchange and mean arterial pressure

HR was monitored continuously using a heart rate monitor (Polar, model FS2c, Kempele, Finland). $\dot{V}O_2$ was measured breath by breath, using open circuit spirometry (Vacumed, Ventura, CA, US) at a sampling rate of 10 s. The gas analyzer was calibrated before each trial using a calibration gas mixture 15% O_2, 6% CO_2 (Praxair, Madrid, Spain). The flowmeter was calibrated using a Jaeger 3L calibration syringe (Vacumed, Ventura, CA, US). Systolic (SBP), and diastolic blood pressures (DBP) were measured on the left arm using an automatic blood pressure monitor (SunTech Tango M2, Morrisville, NC, US). Mean arterial pressure (MAP) was calculated as [(2 x diastolic blood pressure) + systolic blood pressure]/3 (Gonzalez-Alonso, Mora-Rodriguez, & Coyle, 1999).

Core, skin and mean body temperature

Core temperature (T_{core}) was continuously measured using a factory-calibrated CorTemp® Ingestible Temperature sensor (CorTemp®, HQInc, Palmetto, FL, US) which participants ingested at least 6-h before the running performance test. Four fast response skin temperature probes (PASCO, model PS-2135, Roseville, CA, US) were placed on the chest, arm, thigh and leg using adhesive mylar foam covers (model PS-2525, PASCO, Roseville, CA, US). Skin temperature (T_{sk}) data was continuously recorded with a data logger (NI USB-6259 BNC, National Instruments, Austin, TX, US). The LabVIEW program was used to record T_{sk} (National Instruments, LabVIEW, 2010). T_{sk} was calculated using the following formula (Ramanathan, 1964):

$$T_{sk} = 0.3 \times (T_{chest} + T_{arm}) + 0.2 \times (T_{thigh} + T_{leg}).$$

Mean body temperature (T_{body}) was calculated using the following formula (Colin, Timbal, Houdas, Boutelie.C, & Guieu, 1971):

$$T_{body} = 0.8 \times T_{core} + 0.2 \times T_{sk}.$$

Heat storage

Heat storage in body tissues was calculated (Mitchell, Nadel, & Stolwijk, 1972) from the formula:

$$HS = 0.97\ BW_{pre}\ (T_{bpost} - T_{bpre})/(SA)\ (t)$$

Where *0.97* is the specific heat of tissue ($W \cdot h^{-1} \cdot kg^{-1} \cdot {}^{o}C^{-1}$); BW_{pre} is the pre-exercise body mass (kg); $(T_{bodypost} - T_{bodypre})$ represents the increase in T_{body} during exercise (ºC); *SA* is the DuBois surface area (m^2) of the body (Du Bois & Du Bois, 1989); and *t* is the elapsed time (h).

Perceptual data

Ratings of perceived exertion (RPE) were assessed using a Borg 6-20 scale (Borg, 1982). Subjective thermal, shivering/sweating and clothing wetness sensations (Ha, Tokura, Tanaka, & Holmer, 1996) were recorded at the end of each bout. Ratings of thermal sensation ranged from 1 (very cold) to 9 (very hot); shivering/sweating sensation ranged from 1 (vigorously shivering) to 7 (heavily sweating); and clothing wetness sensation ranged from 1(dry) to 4 (wet).

Data Analysis

Means ± SD are provided for all data. A repeated-measures (garment condition x time) analysis of variance (SPSS version 17.0, Chicago, IL, US) was used to determine significant differences between the UBCG and control conditions. A Tukey's honest significant test was performed *post-hoc* to determine individual significant differences. A paired *t test* was used to compare weight loss and sweat rate between garment conditions. Effect sizes (ES) were calculated according to Cohen's *d (Cohen, 1988)* and were interpreted as trivial (< 0.2, trivial), small (0.2-0.49), moderate (0.5-0.79) and large (≥ 0.8). Statistical significance was set as $p < 0.05$.

3. Results

Participants were euhydrated before each trial with a urine specific gravity < 1020. No significant differences in W_{loss} (1.04 ± 0.31% vs. 1.01 ± 0.49% for UBCG and CON respectively; P=0.76, ES=0.07, trivial effect) or sweat rate (13.6 ± 5.3 g·min^{-1} vs. 13.4 ± 7.6 g·min^{-1}; $p = .84$, $ES = 0.03$, trivial effect) were observed between garment conditions after the trial.

T_{core} significantly increased over time ($p < .001$) in both garment conditions (Figure 1a). A significantly higher ($p = .04$, $ES = 0.64$, moderate effect) T_{core} was observed in the UBCG (38.09 ± 0.26 ºC) versus CON (37.91 ± 0.30 ºC) condition at the end of exercise. Furthermore, T_{body} was significantly higher ($p = 0.01$, $ES =$ 0.93, large effect) in the UBCG (36.94 ± 0.23 ºC) than CON (36.73 ± 0.22 ºC) condition at the end of exercise (Figure 1b). Thermal sensation (Figure 2a) was significantly higher ($p = .02$, $ES = 0.65$, moderate effect) in the UBCG (8.0 ± 0.4) than CON (7.5 ± 1.0) condition after 1-h exercise. RPE was significantly lower in UBCG at Bout 1 ($p = .03$, $ES = 0.56$, moderate effect) and 2 ($p = .02$, ES=0.81, large effect), but did not differ at the end (10.9 ± 1.1 for UBCG vs. 11.1 ± 1.2 for CON; $p = .44$, $ES = 0.13$, trivial effect) (Figure 2b). T_{sk} ($p = .57$, $ES = 0.12$, trivial effect) and heat storage ($p = .13$, $ES = 0.52$, moderate effect) did not differ between garment conditions throughout the test. HR, $\dot{V}O_2$, $\dot{V}CO_2$, RER, VE, MAP, sweating sensation and clothing wetness sensation were not statistically different between conditions during exercise or recovery (Table 2).

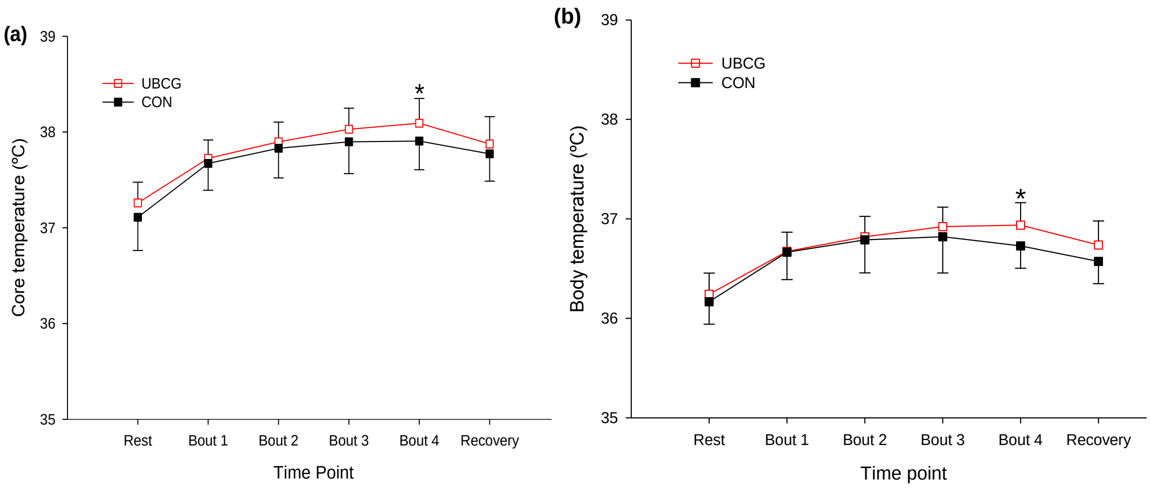

Figure 1. *Core temperature **(a)** and mean body temperature **(b)** during experimental trial. □, Upper body compression garment (UBCG); ■, Control (CON). * Significantly different between garment conditions (p < .05).*

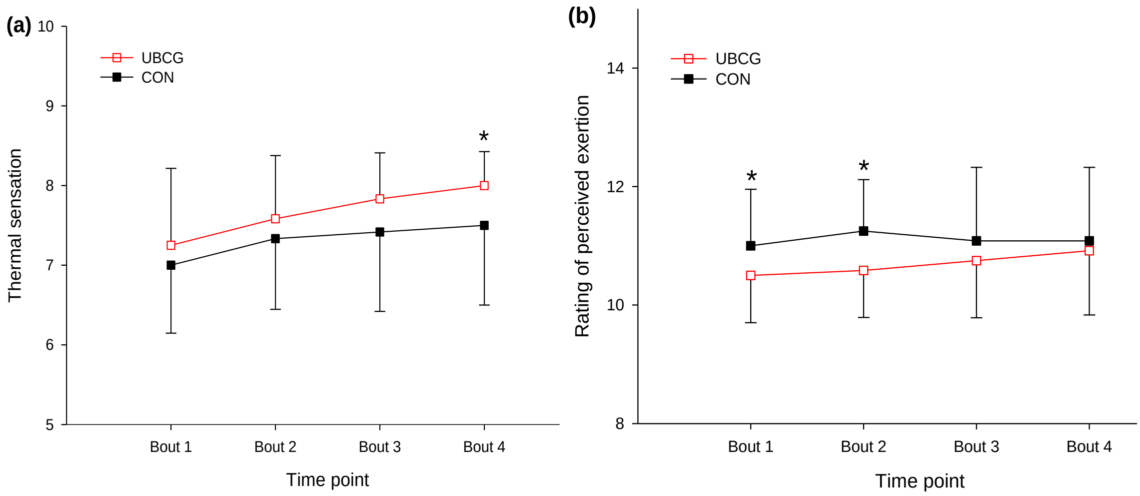

Figure 2. *Thermal sensation **(a)** and rating of perceived exertion **(b)** during experimental trial. □, Upper body compression garment (UBCG); ■, Control (CON). * Significantly different between garment conditions ($p < .05$).*

Table 2. *Physiological and perceptual responses after 1-h cycling exercise and 10 min passive recovery*

	Exercise		Recovery	
	UBCG	**CON**	**UBCG**	**CON**
HR (bpm)	117 ± 9	113 ± 8	80 ± 10	79 ± 10
$\dot{V}O_2$ (ml·kg^{-1}·ml^{-1})	1.7 ± 0.3	1.7 ± 0.4	0.4 ± 0.1	0.4 ± 0.1
$\dot{V}CO_2$ (ml·kg^{-1}·ml^{-1})	1.4 ± 0.3	1.4 ± 0.3	0.3 ± 0.1	0.3 ± 0.1
RER	0.83 ± 0.04	0.82 ± 0.05	0.75 ± 0.07	0.74 ± 0.05
VE (l·min^{-1})	39.9 ± 7.6	38.6 ± 9.9	9.6 ± 2.1	9.1 ± 2.0
MAP (mmHg)	113 ± 7	110 ± 12	92 ± 7	93 ± 10
Sweating sensation	5.6 ± 0.7	5.7 ± 0.7	-	-
Clothing wetness sensation	2.7 ± 0.8	2.8 ± 0.6	-	-

Abbreviations: HR, heart rate; $\dot{V}O_2$, oxygen consumption; $\dot{V}CO_2$, carbon dioxide production; RER, respiratory exchange ratio; VE, ventilation; MAP, mean arterial pressure.

4. Discussion

The aim of the present study was to evaluate the effects of an UBCG during cycling in a temperate environment in 66-year-old trained cyclists. Results showed that wearing an UBCG during exercise led to a significantly higher T_{core} and T_{body} (Figure 1). Participants also perceived a higher thermal sensation when wearing the UBCG at the end of exercise (Figure 2a). Several studies have proposed that CG can cause thermal insulation during exercise (Goh et al., 2011; Houghton et al., 2009), may negatively affect exercise performance in the heat (Goh et al., 2011) and/or cause mild increases in thermoregulatory responses (MacRae et al., 2012). However, previous studies investigating the effects of a similar UBCG in young population did not find differences in T_{core} or T_{body} during exercise in thermoneutral (Leoz-Abaurrea et al., 2016) or hot (Leoz-Abaurrea et al., 2015) environments. In those studies, constant air fans were used at different ambient temperatures. The use of electric fans have been shown to be effective cooling devices even in hot and humid environments (Ravanelli, Hodder, Havenith, & Jay, 2015) dissipating excess of heat and reducing heat storage (Saunders, Dugas, Tucker, Lambert, & Noakes, 2005). In the present study, we eliminated the influence of electric fans to investigate the potential effects of UBCG, based on previous studies (Leoz-Abaurrea et al., 2015; Leoz-Abaurrea et al., 2016) in which garment differences may have been hidden. For instance, MacRae et al. (2012) stated that the use of constant airflow "likely mitigated" the adverse thermoregulatory and cardiovascular effects observed in full-body CG in temperate conditions. These authors also suggested that those physiological effects might be more pronounced with the absence of a constant fan. Hence, it was reasonable to exclude this element in this study.

Ageing alters the physiological capacity to dissipate the heat, reducing whole body evaporative heat loss with time (Stapleton et al., 2015). One reason for this thermoregulatory impairment could be the attenuation of sweat rates due to age-related reductions in cholinergic stimulation sensitivity and/or skin structure (i.e. secretory capacity of the sweat glands) deterioration (Inbar, Morris, Epstein, & Gass, 2004). Furthermore, the pressure exerted on the skin by CG may produce an inhibitory effect on sweat rate (Ogawa, Asayama, Ito, & Yoshida, 1979) and could produce quicker increases in T_{core} when wearing in warm-hot environments (Tanaka, Midorikawa, & Tokura, 2006). Therefore, the pressure exerted by UBCG during exercise may accelerate the appearance of hyperthermia in older adults. However, it was not the case in this study because no differences in sweat rate or W_{loss} were observed between garments. Present results are in agreement with previous studies where similar garments were worn (Leoz-Abaurrea et al., 2015; Leoz-Abaurrea et al., 2016). The outcomes from this study go against manufacturer´s claim of an improved sweat efficiency that those garments could have, and demonstrate the inefficacy of UBCG to dissipate the heat more efficiently than a control garment. The lack of differences in the previously mentioned parameters suggest that the pressure exerted by the UBCG was not responsible for a reduced sweating rate. However, it was responsible for an increased thermoregulatory strain. In this sense, MacRae et al. (2012) proposed that garment coverage *per se*, had more influence in the thermoregulatory strain than the differences in the applied pressures when wearing correctly-sized CG, over-sized CG or control garment. Further studies investigating the causes of thermoregulatory strain caused by CG are required to elucidate this.

Participants felt warmer when wearing UBCG than CON (Figure 2a). This finding is in agreement with a previous study (MacRae et al., 2012) that found greater thermal states when wearing full-body CG. Furthermore, it was consistent with the thermoregulatory responses reported in the present study. Presumably, the significantly greater thermoregulatory responses observed wearing the UBCG at the end of exercise made participants perceive higher thermal sensation. Conversely, RPE (Figure 2b) was significantly lower during the first half of the protocol (Bout 1 and Bout 2). It is important to note that subjects were not blinded to the garment condition. This previous knowledge about the possible benefits of wearing UBCG may have had a positive psychological effect on participants and influenced their perceptions. Nevertheless, participants finished with a similar RPE at the end of both exercise trials. Sweating and clothing wetness sensation did not differ between garments either. Perhaps, the absence of differences observed in sweat rate or W_{loss} between garments may explain the similar perceptual responses observed (Table 2).

The cardiovascular responses measured in the present study (HR and MAP) did not differ between garment conditions during exercise (Table 2). While some studies have suggested that the use of CG may lower the HR (Lovell, Mason, Delphinus, & McLellan, 2011) and enhance overall circulation (Bringard, Perrey, & Belluye, 2006), the majority of the studies have failed to find differences in cardiovascular responses (Dascombe, Laursen, Nosaka, & Polglaze, 2013; Leoz-Abaurrea et al., 2015; Leoz-Abaurrea et al., 2016; Sperlich, Born, Zinner, Hauser, & Holmberg, 2014). Furthermore, there were no significant differences in the respiratory gas exchange between garments during the trial. These results support previous studies assessing UBCG (Dascombe et al., 2013; Leoz-Abaurrea et al., 2015; Leoz-Abaurrea et al., 2016; Sperlich et al., 2014) and full-body CG (MacRae et al., 2012) during exercise. Thus, the present findings suggest that the use of UBCG during exercise in a temperate environment do not help mitigating cardiorespiratory strain in trained older adults.

In summary, UBCG increased thermoregulatory strain during exercise in 66-year-old trained cyclists. Greater T_{core}, T_{body} and thermal sensation were observed in the UBCG condition after 1-h of cycling in a temperate environment without airflow. These possible negative thermoregulatory effects when wearing UBCG suggest that these type of garments should not be used by older adults during moderate exercise in a temperate environment, considering that they may accelerate the appearance of hyperthermia.

References

- Ali, A., Caine, M. P., & Snow, B. G. (2007). Graduated compression stockings: physiological and perceptual responses during and after exercise. *Journal of Sports Sciences, 25*(4), 413-419. doi:10.1080/02640410600718376

- Ali, A., Creasy, R. H., & Edge, J. A. (2010). Physiological effects of wearing graduated compression stockings during running. *European Journal of Applied Physiology, 109*(6), 1017-1025. doi:10.1007/s00421-010-1447-1

- Armstrong, C. G., & Kenney, W. L. (1993). Effects of age and acclimation on responses to passive heat exposure. *J Appl Physiol (1985), 75*(5), 2162-2167. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8307874

- Barwood, M. J., Corbett, J., Feeney, J., Hannaford, P., Henderson, D., Jones, I., & Kirke, J. (2013). Compression garments: no enhancement of high-intensity exercise in hot radiant conditions. *International Journal of Sports Physiology and Performance, 8*(5), 527-535. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23349313

- Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise, 14*(5), 377-381. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7154893

- Bringard, A., Perrey, S., & Belluye, N. (2006). Aerobic energy cost and sensation responses during submaximal running exercise--positive effects of wearing compression tights. *International Journal of Sports Medicine, 27*(5), 373-378. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16729379

- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*: Erlbaum: Mahwah.

- Colin, J., Timbal, J., Houdas, Y., Boutelie.C, & Guieu, J. D. (1971). Computation of Mean Body Temperature from Rectal and Skin Temperatures. *Journal of Applied Physiology, 31*(3), 484-&. Retrieved from <Go to ISI>://WOS:A1971K371800027

- Chatard, J. C., Atlaoui, D., Farjanel, J., Louisy, F., Rastel, D., & Guezennec, C. Y. (2004). Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *European Journal of Applied Physiology, 93*(3), 347-352. doi:10.1007/s00421-004-1163-9

- Dascombe, B., Laursen, P., Nosaka, K., & Polglaze, T. (2013). No effect of upper body compression garments in elite flat-water kayakers. *European journal of sport science, 13*(4), 341-349. doi:10.1080/17461391.2011.606842

- Du Bois, D., & Du Bois, E. (1989). A formula to estimate the approximate surface area if height and weight be known. 1916. *Nutrition (Burbank, Los Angeles County, Calif.), 5*(5), 303.

- Dufour, A., & Candas, V. (2007). Ageing and thermal responses during passive heat exposure: sweating and sensory aspects. *European Journal of Applied Physiology, 100*(1), 19-26. doi:10.1007/s00421-007-0396-9

- Goh, S. S., Laursen, P. B., Dascombe, B., & Nosaka, K. (2011). Effect of lower body compression garments on submaximal and maximal running performance in cold (10 degrees C) and hot (32 degrees C) environments. *European Journal of Applied Physiology, 111*(5), 819-826. doi:10.1007/s00421-010-1705-2

- Gonzalez-Alonso, J., Mora-Rodriguez, R., & Coyle, E. F. (1999). Supine exercise restores arterial blood pressure and skin blood flow despite dehydration and hyperthermia. *American Journal of Physiology, 277*(2 Pt 2), H576-583. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10444482

- Gonzalez-Alonso, J., Teller, C., Andersen, S. L., Jensen, F. B., Hyldig, T., & Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *J Appl Physiol (1985), 86*(3), 1032-1039. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10066720

- Ha, M., Tokura, H., Tanaka, Y., & Holmer, I. (1996). Effects of two kinds of underwear on thermophysiological responses and clothing microclimate during 30 min walking and 60 min recovery in the cold. *Applied Human Science, 15*(1), 33-39.

- Houghton, L. A., Dawson, B., & Maloney, S. K. (2009). Effects of wearing compression garments on thermoregulation during simulated team sport activity in temperate environmental conditions. *Journal of Science and Medicine in Sport, 12*(2), 303-309. doi:10.1016/j.jsams.2007.09.004

- Inbar, O., Morris, N., Epstein, Y., & Gass, G. (2004). Comparison of thermoregulatory responses to exercise in dry heat among prepubertal boys, young adults and older males. *Experimental Physiology, 89*(6), 691-700. doi:10.1113/expphysiol.2004.027979

- Kenney, W. L., & Munce, T. A. (2003). Invited review: aging and human temperature regulation. *J Appl Physiol (1985), 95*(6), 2598-2603. doi:10.1152/japplphysiol.00202.2003

- Kenny, G. P., Yardley, J., Brown, C., Sigal, R. J., & Jay, O. (2010). Heat stress in older individuals and patients with common chronic diseases. *CMAJ: Canadian Medical Association Journal, 182*(10), 1053-1060. doi:10.1503/cmaj.081050

- Larose, J., Boulay, P., Sigal, R. J., Wright, H. E., & Kenny, G. P. (2013). Age-related decrements in heat dissipation during physical activity occur as early as the age of 40. *PloS One, 8*(12), e83148. doi:10.1371/journal.pone.0083148

- Leoz-Abaurrea, I., Tam, N., & Aguado-Jimenez, R. (2015). Impaired cardiorespiratory responses when wearing an upper body compression garment during recovery in a hot environment (40 masculineC). *Journal of Sports Medicine and Physical Fi ness*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/25784398

- Leoz-Abaurrea, I., Tam, N., & Aguado-Jiménez, R. (2016). Heat dissipating upper body compression garment: Thermoregulatory, cardiovascular, and perceptual responses. *Journal of Sport and Health Science*. doi:http://dx.doi.org/10.1016/j.jshs.2016.01.008

- Lovell, D. I., Mason, D. G., Delphinus, E. M., & McLellan, C. P. (2011). Do compression garments enhance the active recovery process after high-intensity running? *J Strength Cond Res, 25*(12), 3264-3268. doi:10.1519/JSC.0b013e31821764f8

- MacRae, B. A., Laing, R. M., Niven, B. E., & Cotter, J. D. (2012). Pressure and coverage effects of sporting compression garments on cardiovascular function, thermoregulatory function, and exercise performance. *European Journal of Applied Physiology, 112*(5), 1783-1795. doi:10.1007/s00421-011-2146-2

- McDermott, B. P., Casa, D. J., Ganio, M. S., Lopez, R. M., Yeargin, S. W., Armstrong, L. E., & Maresh, C. M. (2009). Acute whole-body cooling for exercise-induced hyperthermia: a systematic review. *J Athl Train, 44*(1), 84-93. doi:10.4085/1062-6050-44.1.84

- Mitchell, J. W., Nadel, E. R., & Stolwijk, J. A. (1972). Respiratory Weight Losses during Exercise. *Journal of Applied Physiology, 32*(4), 474-&. Retrieved from <Go to ISI>://WOS:A1972M122600007

- Ogawa, T., Asayama, M., Ito, M., & Yoshida, K. (1979). Significance of skin pressure in body heat balance. *Japanese Journal of Physiology, 29*(6), 805-816. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/541903

- Ramanathan, N. L. (1964). A New Weighting System for Mean Surface Temperature of the Human Body. *Journal of Applied Physiology, 19*, 531-533. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14173555

- Ravanelli, N. M., Hodder, S. G., Havenith, G., & Jay, O. (2015). Heart rate and body temperature responses to extreme heat and humidity with and without electric fans. *JAMA, 313*(7), 724-725. doi:10.1001/jama.2015.153

- Rey, G., Jougla, E., Fouillet, A., Pavillon, G., Bessemoulin, P., Frayssinet, P., . . . Hemon, D. (2007). The impact of major heat waves on all-cause and cause-specific mortality in France from 1971 to 2003. *International Archives of Occupational and Environmental Health, 80*(7), 615-626. doi:10.1007/s00420-007-0173-4

- Saunders, A. G., Dugas, J. P., Tucker, R., Lambert, M. I., & Noakes, T. D. (2005). The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. *Acta Physiologica Scandinavica, 183*(3), 241-255. doi:10.1111/j.1365-201X.2004.01400.x

- Smith, C. J., & Havenith, G. (2011). Body mapping of sweating patterns in male athletes in mild exercise-induced hyperthermia. *European Journal of Applied Physiology, 111*(7), 1391-1404. doi:10.1007/s00421-010-1744-8

- Sperlich, B., Born, D. P., Zinner, C., Hauser, A., & Holmberg, H. C. (2014). Does upper-body compression improve 3 x 3-min double-poling sprint performance? *International Journal of Sports Physiology and Performance, 9*(1), 48-57. doi:10.1123/ijspp.2013-0137

- Stapleton, J. M., Poirier, M. P., Flouris, A. D., Boulay, P., Sigal, R. J., Malcolm, J., & Kenny, G. P. (2015). Aging impairs heat loss, but when does it matter? *J Appl Physiol (1985), 118*(3), 299-309. doi:10.1152/japplphysiol.00722.2014

- Tanaka, S., Midorikawa, T., & Tokura, H. (2006). Effects of pressure exerted on the skin by elastic cord on the core temperature, body weight loss and salivary secretion rate at 35 degrees C. *European Journal of Applied Physiology, 96*(4), 471-476. doi:10.1007/s00421-005-0099-z

CHAPTER 4

Running performance while wearing a heat dissipating compression garment in male recreational runners *

* **Leoz-Abaurrea I**, Santos-Concejero J, Grobler L, Engelbrecht L, Aguado-Jiménez R. Running performance while wearing a heat dissipating compression garment in male recreational runners. J Strength Cond Res. 2016 Apr 21.

Abstract

The aim of this study was to investigate the effects of a *heat dissipating* compression garment (CG) during a running performance test. Ten male recreational runners (mean ± SD: age 23 ± 3 years; $\dot{V}O_{2max}$ 55.8 ± 4.8 ml·kg^{-1}·min^{-1}) completed two identical sessions wearing either CG or conventional t-shirt (CON). Each trial included a 45-min run at 60% of the peak treadmill speed (PTS) followed by a time to exhaustion (TTE) run at 80% of the PTS and a 10-min recovery period. During the tests, thermoregulatory and cardiovascular responses were monitored. Participants wearing the CG displayed an impaired running performance (508 ± 281 s *vs*. 580 ± 314 s, P=0.046; ES=0.24). In addition, a higher respiratory exchange ratio (1.06 ± 0.04 *vs*. 1.02 ± 0.07, P=0.01. ES=0.70) was observed at TTE when wearing the CG in comparison to CON. Changes in core temperature did not differ between garments after the 45-min run (P=0.96, ES=0.03) or TTE (1.97 ± 0.32 ºC *vs*. 1.98 ± 0.38 ºC; P=0.93, ES=0.02) for CG and CON respectively. During recovery, significantly higher heart rate and blood lactate values were observed when wearing CG (P<0.05). These findings suggest that the use of a heat dissipating CG may not improve running performance in male recreational runners during a running performance test to exhaustion.

Keywords: Upper body, time to exhaustion, exercise, cardiorespiratory strain, core temperature

OVERALL CONCLUSIONS OF THE RESEARCH STUDIES

After the evaluation of a heat dissipation upper body compression garment as a novel strategy to reduce body temperature increments, we conclude that:

1. The use of a heat dissipating upper body compression garment does not provide any thermoregulatory benefit during inttermitent moderate exercise in a thermoneutral environment in untrained participants. (study 1)
2. However, the results from the study 1 appear to demonstrate the efficacy of wearing a heat dissipating upper body compression garment during recovery process, which suggests that it might be a useful thermoregulatory tool after exercise. (study 1)
3. Wearing an upper body compression garment may be beneficial for intermittent exercise-based sports where there is a player rotation system such as, volleyball, handball, futsal; or individual sports with resting periods throughout the game (tennis). (study 1)
4. The use of an upper body compression garment does not mitigate thermoregulatory or cardiorespiratory strain during moderate inttermitent cycling in a hot environment in untrained participants. (study 2)
5. Wearing an upper body compression garment may increase cardiorespiratory strain during active recovery in a hot environment. This type of garments may increase oxygen consumption and carbon dioxide production values and result in a smaller reduction in heart rate. (study 2)
6. Heat dissipating upper body compression garments may increase thermoregulatory responses (significantly greater core and body temperature, and thermal sensations) during moderate exercise in a temperate environment in 66-year-old trained cyclist. (study 3)
7. These possible negative thermoregulatory effects when wearing upper body compression garments suggest that these type of garments should not be used by older adults during moderate exercise in a temperate environment, considering that they may accelerate the appearance of hyperthermia. (study 3)
8. The use of compression garments do not benefit the thermoregulatory responses (changes in core temperature) during a running performance test to exhaustion in male recreational runners. This apparent lack of compression

garments effect on thermoregulatory responses, is in agreement with previous research (study 1 and 2), and it probably indicates that this type of garment is ineffective (in terms of thermoregulation at least) during moderate or high intensity exercise. (study 4)

9. The use of an upper body compression garment does not provide any ergogenic effect on running performance. Moreover, it could shorten the time to exhaustion during a running performance test. (study 4)

10. Furthermore, it might increase blood lactate and heart rate values during passive recovery after high intensity exercise, therefore, it cannot be stated that the use of these garments serves as an ergogenic aid during either a running performance test to exhaustion or short-term passive recovery. Runners should be aware of these results during competition and following recovery when wearing compression garments in the future. (study 4)

Proposed research studies for the future and limitations

In an attempt to design a similar protocol for all the studies, the present thesis planned four hypothetical situations:

a) Young participants exercising in a thermoneutral environment

b) Young participants exercising in a hot environment

c) Older adults exercising in a thermoneutral environment

d) Older adults exercising in a hot environment

We aimed to compare the effects of a heat dissipating upper boy compression garment in two distiguished age gropus during exercise at two different environmental conditions However, due to the negative experiences suffered with the youngest participants in the hot environment, we decided not to perform the same protocol with older adults and finally we modified it into a single study: older adults exercising in a temperate environment. Unfortunately, these comparisons between the proposed two age groups and environmental conditions were not possible. Future research should focus on this aspect in order to appreciate the possible physiological and perceptual differences in respect of age and/or ambient temperature.

There are also many physiological variables that we would have wished to measure but they were not possible due to lack of experience and/or resources. As an example, blood flow is an important measurement that literature has shown to increase during exercise when wearing lower body compression garments, and it is and aspect that we have tried to discuss in our manuscripts. Future research is needed to confirm whether there is an increased blood flow when upper body compression garments are used.